PHYSICS LABORATORY MANUAL

for Senior Secondary Classes

Class XII

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राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

November 1989
Kartika 1911

P.D. 70T-DPG

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Published at the Publication Department by the Secretary, National Council of Educational Research and Training, Sri Aurobindo Marg, New Delhi-110 016, photocomposed at Shagun Composers, 92-B, Krishna Nagar, Street No 4, Safdarjung Enclave, New Delhi-110 029 and printed at Indian Printing Works, Jhandewalan, New Delhi-110 055

Foreword

The National Council of Educational Research and Training (NCERT) set up an Advisory Committee under the chairmanship of Prof. C.N.R Rao, Director, Indian Institute of Science, Bangalore, in July 1986, for the development of instructional packages in science and mathematics from the upper primary to the senior secondary stage, on the lines of the National Education Policy (1986). Different writing teams headed by eminent scientists and science educationists were formed. The Physics writing team headed by Prof. V.G. Bhide, the then Vice-Chancellor, Poona University, Pune, decided that a laboratory manual would form a part of the new instructional package. The syllabus in physics prepared for the senior secondary stage by the team formed the basis for preparing the textbook and the present 'Physics Laboratory Manual'. These two books were prepared simultaneously and go hand in hand. The main purpose of the manual is to integrate the practical work in physics with the content presented in the textbook and to provide the students a fuller view of the subject. The group of authors have borne in mind the limited resources available at present in an average school, while preparing this manual.

While preparing this manual recent efforts to improve physics practical work made at the University of Rajasthan, Jaipur, the Punjab University, Chandigarh, the Regional College of Education, Mysore and the Department of Education in Science and Mathematics (DESM) of NCERT, Physics Curriculum Development Projects in U.K., U.S.A., and U.S.S.R., besides experiences of a recent laboratory survey conducted by DESM, were kept in view by the team.

My appreciation and thanks are due to Prof. V.G. Bhide, Chairman of this Team, for providing the leadership to the three groups formed by the teams working at Bangalore-Mysore, Bombay-Pune, and Delhi, and to all the authors of this laboratory manual for the hard work put in by them in preparing the draft manuscript, for revising it to incorporate the suggestions received in four workshops organised in connection with this manual at (i) DESM, NCERT; (ii) Jnana Prabodhini Prashala, Pune, and (iii) University of Poona, Pune. I thank all the participants of these workshops for their contributions. Thanks are also due to Prof. S.R. Choudhary of the Department of Physics and Astrophysics, University of Delhi for guidance provided by him in developing the manuscript of a portion of this manual.

I would like to record my thanks to Prof. B. Ganguly, Head, DESM and to Prof. Ved Ratna, Coordinator and General Editor for this Laboratory Manual, who have borne much of the burden of organising and steering through the programme of preparation of this Manual as a part of the instruction package in Physics for the senior secondary stage. My thanks

are also due to Mr C.N. Rao, Head, Publication Department, NCERT, and his Publication Team for ensuring the quality of production of this Laboratory Manual.

Suggestions for improvement of the book will be most welcome

P. L. MALHOTRA
Director
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Preface

The National Policy on Education adopted in 1986, the plan of action evolved to implement the accepted National Policy, and the countrywide debate thereon led to a decision that the teaching of science should be introduced in an integrated way and pursued up to Class X as a part of the study of Nature without compartmentalising it into narrow disciplines such as physics, chemistry, botany, zoology, etc. With this background of science, it was further decided to teach physics as a separate subject in Classes XI and XII. In order to prepare a total package of curricular materials for Classes XI and XII working groups consisting of university professors, school teachers and NCERT experts were constituted.

The Physics working group, after long deliberation, considered it necessary to initiate a new approach to the teaching and learning of physics at the school level. This approach is essentially based on the active participation of the students in the learning process through experimentation, supplemented by demonstration by the teachers, oriented out-of-class activity by the students and discussion leading to the understanding of the basic concepts in physics without the loss of mathematical rigour. The working group desired to integrate the classroom text, the laboratory text and the comprehensive exercises into one single book in order to bring out the fact that physics is an experimental science. Although unfortunately, it has not been possible to bring out the classroom text and the laboratory text in a single volume, efforts have been made to maintain close relationship between the laboratory experiments and demonstrations with the concepts dealt with and developed in the classroom text.

The practical work described in the laboratory text has been classified into three types: (a) demonstrations (designated by D along with their serial numbers) recommended to be shown, or better still, to be collectively done by the students and the teacher and discussed by the teacher in the classroom; (b) laboratory experiments (designated by E along with their serial numbers) to be carried out by the students in the school laboratory, and (c) out-of-the-classroom activities (designated by A along with their serial numbers) recommended to be undertaken by the students at home or elsewhere. The activities mentioned in the book are indeed illustrative and are supposed to excite the curiosity of the student. Amongst the laboratory experiments, there are some experiments designated as SE which are meant to develop the skills in the students. Both the demonstration experiments and the activities are indicative and we hope that the teachers will design new and effective demonstrations and the students will undertake activities or open-ended enquiries related to the concepts they learn in the classroom. It is hoped that the students will eventually be examined in the practical examination with reference to laboratory experiments only.

The entire content of this laboratory text has been divided into five themes. Material presented under themes I (Electrostatics); II (Current Electricity); III (Magnetism and Electromagnetism); IV (Electromagnetic Induction and Varying Currents); and V (Optics and Modern Physics) have been organized around topics dealt with and developed in related chapters (chapters 1 and 2; chapters 3 and 4; chapters 5 and 6; chapters 7, 8 and 9; chapters 10, 11, 12, 13 and 15 respectively) We have attempted in these themes to present a topic developed in the classroom text and then suggested and described laboratory experiments, demonstrations and oriented activities aimed at clarifying the concept related to it. It is hoped that such an organisation of the laboratory manual would be found useful in teaching the subject and in bringing out a close linkage between laboratory work and classroom theory.

The description of the laboratory experiments differs markedly from that found in traditional books for practical work. The latter are rather the cook-book type in which the entire procedure is supposed to be followed mechanically, thereby killing initiative and the spirit of enquiry. We have attempted to describe in this manual both the 'why' and 'how' of the procedure of an experiment. Notes have been added after many experiments, which explain the important precautions, alternative procedures, improvisations and extension of the experiment in the form of activities and/or project work Only in a few experiments, a table of observations is given and these are only illustrative We feel that the students should design their own table of observations in accordance with the procedure followed by them. Likewise, the necessary theoretical background of the experiment presented under the subheading 'Theory' is only a few experiments where it is necessary. Efforts have been made not to repeat the content of the textbook, except where it is essential for clarity of expression for continuity.

Traditionally, demonstration experiments are supposed to be done by the teachers without any participation by the students. Consequently, demonstration experiments are seldom described in the laboratory manual. However, we feel that students can and should participate in the process of setting up, demonstrating and improvising these demonstrations. In our opinion this participation will excite the students which may ultimately lead to very innovative demonstrations Indeed, we feel that such participation by the students could even be treated as performing a project for examination and/or for demonstrating in science exhibitions provided it reflects the evidence of creativity It is with this perspective in mind that we have described the demonstration experiments making clear the essential observations to be made by the students and also how to perform it. We sincerely hope that the teachers will not only demonstrate as many experiments as possible but also design and develop a number of demonstration experiments.

Oriented activities to be undertaken by the students have been rather briefly stated because further details of these will depend very much upon local situations and materials available for doing them. These activities are illustrative and students should be encouraged to undertake a number of such related activities. A few of these activities can, in fact, be enlarged in their scope to form a small project.

In recent years, several efforts have been made, in India and abroad, to improve physics practical work. This has led to the designing, development and trial of a number of novel experiments based on any one or more of the following

1 To provide to the students novel and exciting experience not hitherto possible with the existing stereotyped apparatus.
2. To reduce the cost of the equipment necessary to carry out an experiment without sacrificing either the accuracy or precision in performing an experiment.
3 To design such apparatus that a number of experiments could be performed.
4. To provide a better and more direct illustration of the principle involved.
5 To design experiments which are simpler, more accurate and easier to perform.

The fruits of such an effort can reach the students only if a curricular renewal programme is simultaneously undertaken. We have taken this opportunity when the entire physics curriculum is being revamped to introduce a number of such non-traditional experiments. However, before including them, hese experiments were actually performed not only by us but by a cross-section of teachers with a view to ensuring that these experiments can indeed be done easily and that they provide more accurate results.

It is hoped that the students and teachers will find these experiments interesting and educative and will be prompted to take the initiative in designing many more of these types of experiments and utilising them in the teaching-learning process It is further hoped that the fact that those who take such initiative will inevitably be a small minority in the beginning will not be used as a reason for keeping these experiments out of the purview of the examination in practical work; otherwise, such initiatives will be killed and no progress will be possible.

The members of the physics curriculum group of the Department of Education in Science and Mathematics, NCERT, have done this work systematically, involving experienced physics teachers from schools and colleges from different parts of the country Four workshops of teachers, including one for review of this material and another for its refinement were organised. I take this opportunity to sincerely thank all the teachers and experts who participated in the workshops for their valued contribution.

Through this laboratory manual, we hope to establish a fruitful and continuing dialogue between the teachers, the students, the senior physicists interested in the improvement of the teaching of physics at the school level so that newer and better experiments can be designed and more exciting activities undertaken by the students We would also be grateful for suggestions improving this manual.

All my colleagues join me in offering grateful thanks to Prof. C.N.R. Rao, who conceived of the idea of working groups, for his guidance and support and to Dr. P.L. Malhotra, Director, NCERT, and Dr. B.Ganguly, Head, DESM for their help in this endeavour.

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THEME I

Electrostatics

ALL matter in the universe is electrical in nature The net charge on a body could be positive, negative or zero. During every reaction, physical, chemical, nuclear, etc , charge on bodies particularly in a reaction is conserved. Thus there is only a separation of charge during the process of charging. Charge can neither be created nor destroyed.

Like charges repel and unlike charges attract. An electric charge produces a force on other charges and also experiences a force due to the presence of other charges in its vicinity. A charge creates an electric field in the surrounding space and any other charge brought into this field experiences a force. Two charges at rest and in motion relative to each other exert a force on each other This force, similar to the gravitational force, is a fundamental force of nature.

TOPIC I TWO KINDS OF CHARGES

1.1 (Demonstration): To demonstrate that some objects acquire an electric charge on rubbing.

(a) Take an ordinary ball pen or a fountain pen with a plastic body. Rub it on dry cloth or on dry hair. After rubbing, bring it near bits of paper[1] spread on the table. You will now notice that it attracts bits of paper, whereas, before so rubbing, it did not attract bits of paper. Thus, the pen acquires the property of attracting bits of paper, and as we shall see later, that this is because the pen has got charged during the process of rubbing. Now roll the pen in between the palms of your two hands. You will notice that the pen has now lost the property of attracting bits of paper, or the pen has now lost its charge. The charge on the pen leaks away to earth through your body.

(b) Take an inflated rubber balloon. Normally it does not stick to the wall. However, on rubbing it with dry cloth, you will notice that it sticks to the wall, attracts bits of paper and, interestingly enough, clings under your dry hand as shown in Fig.1 1.

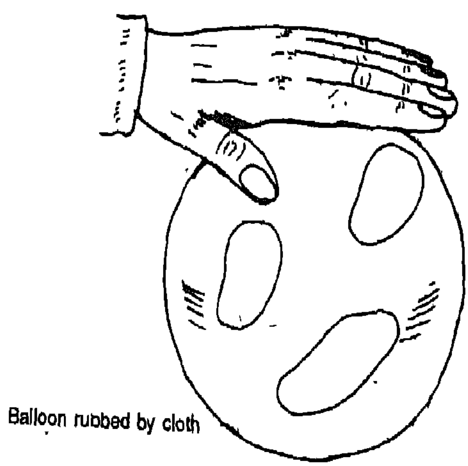


Fig. 1.1 *Charged balloon clings under your dry hand.*

[1] For better results, use small bits of tissue paper cut to about 2mm x 2mm size

1.2 (Activity): Materials which get electrified on rubbing.

(a) Take following pairs of bodies and rub one amongst the pair with the other in the pair and see whether they get charged by bringing them close to the bits of paper spread on a table.

(i) A glass rod and dry silk cloth
(ii) An ebonite rod and woollen cloth
(iii) A cellulose acetate strip or perspex strip and dry cotton
(iv) A vinylite strip or polythene (a popular name for polyethylene) strip and wool
(v) A metal rod with an ebonite handle and dry silk cloth
(vi) A dry peacock feather and folded paper
(Place the feather in between the folds and pull it a few times)
(vii) Polythene strip and pages of the book.
(Place polythene strip in between the pages of a book and pull it, repeat it several times)

(b) Look around and take several pairs of objects and rub one amongst the other. List those which get charged and those which don't.

1.3 (Demonstration): To demonstrate that there are two kinds of charges and that like charges repel and unlike charges attract.

(a) Rub a glass rod with a piece of silk cloth. Place this glass rod horizontally in a wire frame suspended by silk or a nylon thread (Fig 1.2). Rub a second glass rod similarly and bring the rubbed end of this glass rod near the rubbed end of the suspended glass rod. You will find that the two glass rods repel each other. Since both the glass rods have been rubbed in a similar fashion, the two must have acquired same kind of charge. From this experiment, we conclude that similar or like charges repel each other.

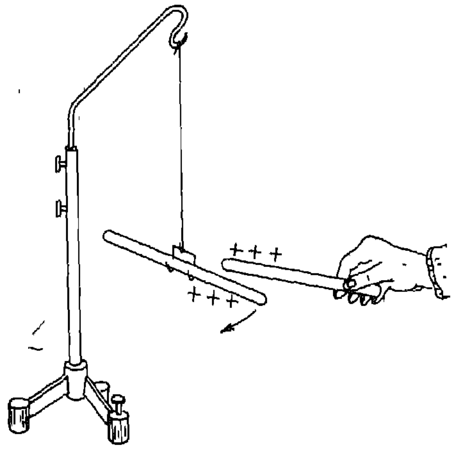


Fig. 1.2 *Similar charges repel each other.*

Repeat the experiment with two ebonite rods rubbed against woollen cloth or vinylite strips with wool In each case, you will notice that like charges repel each other.

(b) Rub a glass rod with a piece of silk cloth Place it as in the previous demonstration horizontally in a wire frame suspended by a silk or a nylon thread. Rub an ebonite rod with a woollen cloth and bring the rubbed end of the ebonite rod near the rubbed end of the suspended glass rod (Fig. 1 3). You will notice that the

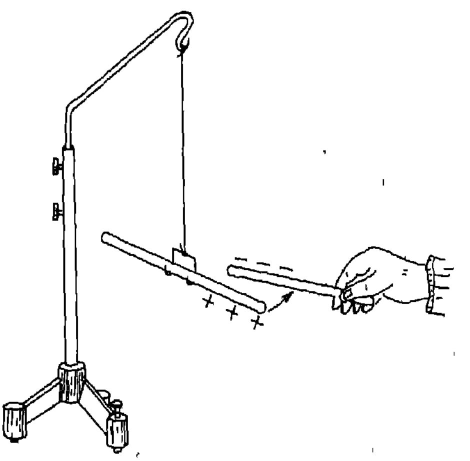


Fig 1.3 *Dissimilar charges attract each other.*

ebonite rod attracts the glass rod. You will thus see that the charged ebonite rod behaves differently from the charged glass rod or the ebonite rod acquires a different kind of charges. Further, this experiment shows that like charges repel each other whereas unlike charges attract each other

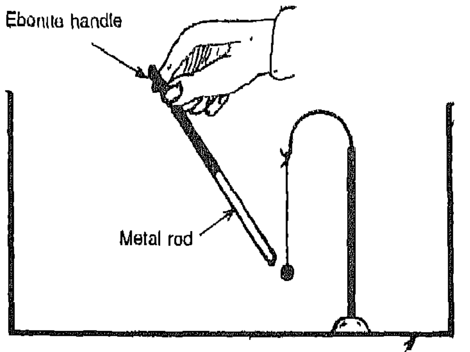
Just as a matter of convention, the charged glass rod and all other charged bodies which behave like it are said to be *Positively charged* Similarly, the charged ebonite rod and all other charged bodies which behave similar to it are said to be *Negatively charged.*

1.4 (Activity): Which of the two kinds of charge do various objects in your environment acquire on rubbing.

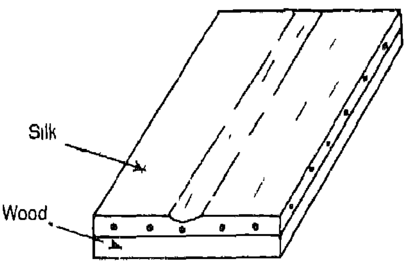
Take pairs of bodies mentioned in activity 1.2a, and also the bodies which you discover in activity 1 2b to acquire charge on rubbing. Find out which of them gets positively charged and which acquires a negative charge. Satisfy yourself that any two bodies charged similarly repel each other. Conversely, bodies having unlike charges attract each other.

1.5 (Demonstration): To demonstrate that when two bodies are rubbed together, both acquire charge; one acquires a positive charge and the other acquires a negative charge.

Take a pith ball (pith is the soft portion inside *Sarkanda* of about 5mm diameter. Coat its outer surface with black waterproof ink or thin layer of aluminium paint (the one containing very small particles of aluminium) to make it conducting. Suspend this coated pith ball[2] with a long dry thread of silk or nylon. (For the success of this experiment, the air in the room must be still or else the suspended pith ball should be enclosed in an enclosure with a transparent window, Fig.1 4a, to observe the movement of the pith ball)



(a)



(b)

Fig. 1.4 (a, b)

Take a metal rod with an ebonite handle[3]. Rub it with dry silk cloth (Few folds of silk cloth are fixed to a block of wood having a small channel of the size of the diameter of the metal rod as shown in Figure 1.4b.) Bring the

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[2]Instead of a pith ball, you can use a sphere made of thermocol or a sphere made of crumpled aluminium foil Whenever, a pith ball is mentioned, it is implied that any one of the three can be used

[3]For a metal rod to be used in these experiments it is necessary to have an ebonite handle or a handle of any similarly insulating material so that the charge developed on the metal rod during friction (rubbing) does not leak through your body to the earth

rubbed metal rod near the coated pith ball. The metal rod attracts the pith ball. On touching the metal rod, the pith ball is repelled (On touching, the pith ball acquires the same charge as that on the metal rod and hence there is repulsion between the metal rod and the pith ball).

Now bring the rubbed silk cloth holding it by the wooden support near the pith ball You will see that whereas the rubbed metal rod repels the pith ball, the silk cloth against which the metal rod was rubbed attracts the pith ball. This clearly shows that both the bodies involved in the process of rubbing acquire charge but the charge on one is opposite to the charge on the other.

Satisfy yourself that this is invariably the case by repeating the above experiment with pairs of bodies mentioned in activity 1.2.

1.6 (Demonstration): To demonstrate that when two bodies get charged by rubbing together, they acquire equal and opposite charge.

Make a sleeve of silk cloth (having several layers of cloth) about 8 cm long, which fits loosely on a metal rod with an ebonite handle. Demonstrate that initially they have no charge, by bringing each in turn near a charged pith ball. Each applies little or no electrical force on the pith ball.

Next, put the metal rod in the sleeve and rub it vigorously. Bring the two together near the pith ball. Again, the pith ball remains unmoved. This shows that there is no net charge on the silk sleeve containing the metal rod. Now take the metal rod out of the sleeve and bring the two in turn near the pith ball. One attracts the ball and the other repells it, showing that they acquire opposite charges. Since the net charge on both together was zero, the magnitude of charge on them is equal[4].

Note. If you observe the effect of rubbed metal rod and sleeve together on the charged pith ball after observing the effect of each individually, chances are that the pith ball may not remain stationary. The reason is that, during the time you observe the effect of each individually on the pith ball, unequal leakage of charge may take place from them.

1.7 (Demonstration): To demonstrate that some materials conduct charge through them easily whereas some others do not.

Take a glass beaker and support a small metal rod AB on top of it as shown. Suspend a pith ball such that it just touches the end A, as shown in Fig.1 5. Take a metal rod CD with an ebonite handle. Rub the rod CD with a silk cloth.

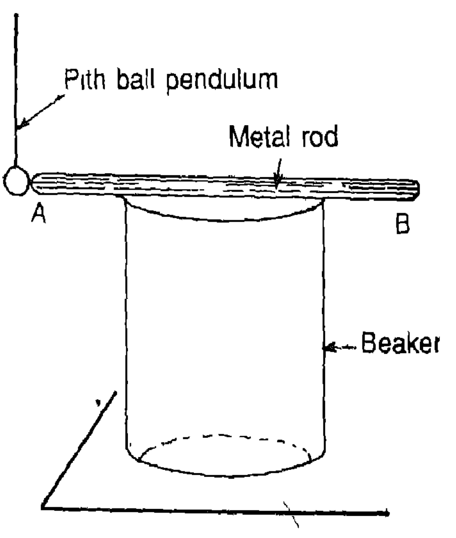


Fig. 1.5

[4]In the process of rubbing, metal rod loses some electrons to the silk cloth getting positively charged whereas the silk cloth having gained these electrons gets negatively charged equally Thus there is merely separation of charges during the process of rubbing

Bring the end C of the charged rod CD in contact with the rod AB at the point B as shown in Fig.1.6. What do you observe? As soon as

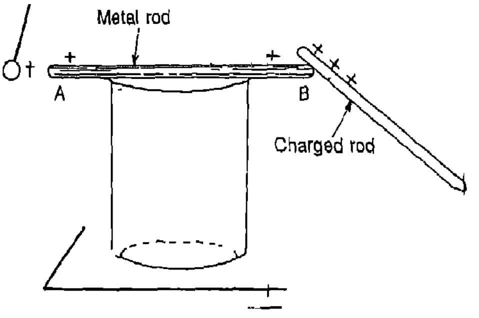


Fig. 1.6

the charged metal rod touches the supported metal rod, the suspended pith ball swings away from the other end of the rod AB as shown in the Fig.1 7. Move the charged metal rod away

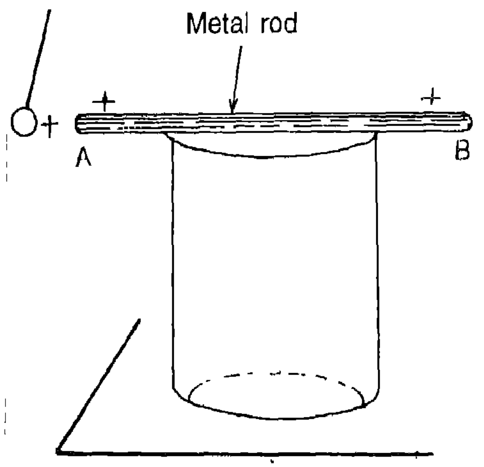


Fig. 1.7

from rod AB. Do you still notice repulsion between the suspended pith ball and the supported metal rod?

When the charged metal rod CD touches end B of the rod AB the charge flows from the rod CD to the rod AB and then to the pith ball in contact with it Both the pith ball and the rod AB acquire the same kind of charge and hence there is a force of repulsion between them.

Repeat this experiment replacing the metal rod AB on the glass beaker by a glass or an ebonite rod EF (Fig.1 8) Observe what hap-

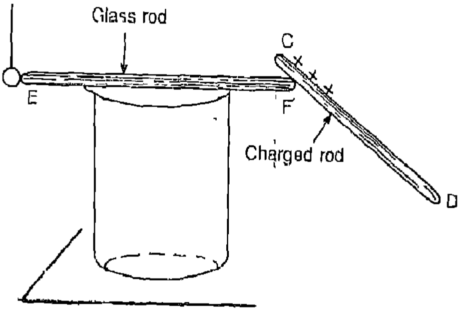


Fig 1.8

pens when the charged metal rod CD is brought in contact of the rod EF The pith ball does not move. We infer that the rod EF (i.e glass or ebonite rod) does not allow the charge to flow from the charged metal rod CD to the pith ball in contact with it.

Those materials which allow the charge to easily flow through them are called conductors, whereas those which do not easily allow the charge to flow through them, are called insulators.

1.8 (Activity): Conductors and insulators in your environment.

You come across in your daily life a large number of materials: wood, glass, plastics, metals, etc. Find out which of them are conductors and which of them are insulators.

ELECTRIC CHARGES ON FAST-MOVING VEHICLES

Electric charges can build up due to friction with air on

an aircraft in flight, creating a potential explosion hazard unless preventive steps are taken The rubber tyres are made slightly conducting so that the accumulated charge leaks away harmlessly on landing In older times, chains used to be hung from the chesis of trucks to make contact with the road, so that any electrostatic charge that develops on it, goes to earth. Now-a-days, you don't see these chains as the rubber tyres are made slightly conducting.

1.9 (Activity): Repulsion among similar charges.

(a) Take a large number (say 50-100) of unspun silk or nylon threads about 20 cm long. Tie them in the middle. Fold them around the centre and suspend them as shown in Figure 1 9a.

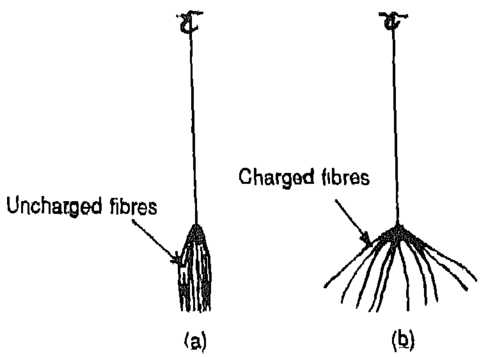


Fig 1.9 (a, b)

Stroke the threads with a dry hand. You may even comb them with a dry comb What do you find on stroking the threads or combing them several times? Explain your observations.

(b) Cut a 10 cm long 3 cm wide polythene strip from a polythene bag. Fold it in the centre and hold it at the fold in one hand, as shown in the Figure 1.10 Rub the two leaves of the strip with dry wool. Observe what happens after rubbing

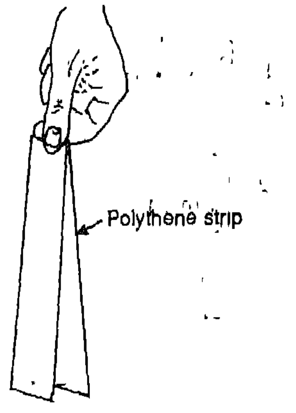


Fig. 1.10

(c) Cut a strip of aluminium foil or metal coated polythene, 20 cm long and 3 cm broad. Fold it in the centre so that the metal coated surface is outside. Fix 1 cm broad adhesive tape as shown in the Figure 1.11, so that you can hold the aluminium strip. Hold the aluminium coated polythene strip by the adhesive tape in one hand. Stroke the suspended strip a few times with silk cloth. What do you observe ? Explain your observation.

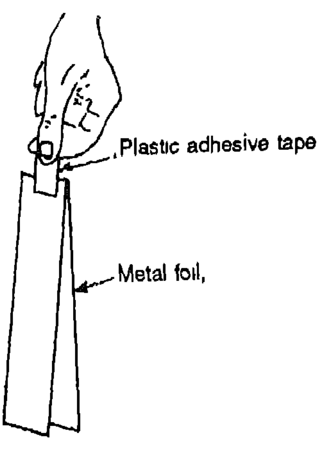


Fig 1.11

1.10 (Activity): To make a simple electroscope and use it to detect charges on bodies.

(a) Bend a metal wire with a knob at one end (you can make such a knob by twisting the wire several times at end A) into the shape shown in Fig, 1.12a. Take about 8 cm long and 1/2 cm

broad strip of thin aluminium foil. Fold it round the middle. See that there are no wrinkles on

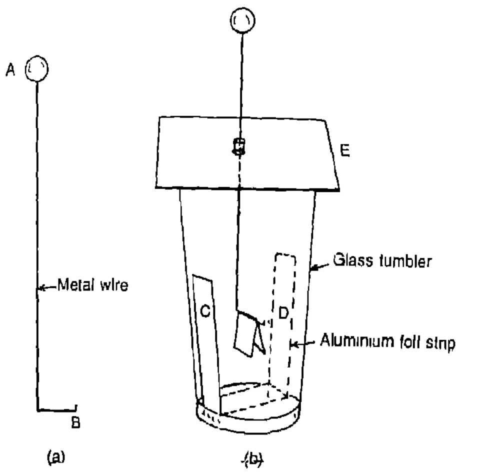


Fig 1 12 (a, b) *An improvised aluminium foil electroscope*

its surface Gently place it on the horizontal arm B of the wire Take a tall glass jar or a tumbler Stick two aluminium foils C and D, 2 cm broad and 10 cm long, on opposite sides of the glass jar. Gently lower the copper wire having the folded aluminium strip on its arm B. Orientation of the wire must be such that C faces one half of the folded aluminium strip and D faces the other half (Fig. 1.12b) E is a cardboard disc to support the wire. This is your electroscope.

With the help of this electroscope, you can show that bodies acquire charge on rubbing. You can also show that during the process of rubbing, the two bodies involved in rubbing acquire opposite kind of charge.

(b) You can make another version of an electroscope as follows. Take two tiny pith balls or thermocole spheres coated with conducting ink or aluminium paint. Tie each ball at one end of a thin copper wire (40 SWG, without enamel) 30 cm long. Suspend them from a thick metal wire placed across a glass jar as shown in the figure. This is your electroscope In this case, the pith balls repel each other on acquiring charge.

In both the cases, you can even measure the deflection of the aluminium foils or the pith balls with the help of a small scale fixed just behind the aluminium foils or pith balls (Fig. 1.13).

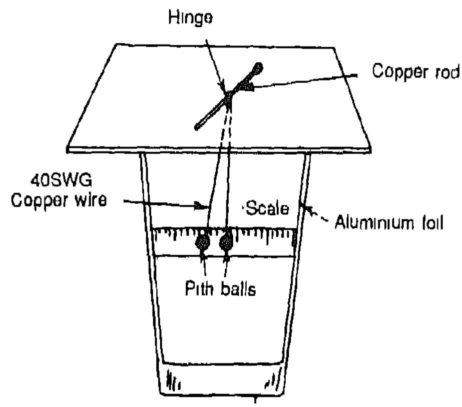


Fig. 1.13 *An improvised pith ball electroscope*

1.11 (Demonstration): To demonstrate the construction of a gold leaf electroscope and its working.

A gold leaf electroscope is schematically shown in Fig. 1 14. It essentially consists of a vertical metal rod A fixed with a metal disc D at one end and a pair of gold leaves L at the other. This metal rod A is fixed in the mouth of a glass bell jar C with the help of an insulating plug P. Now-a-days, thin aluminium foils are used

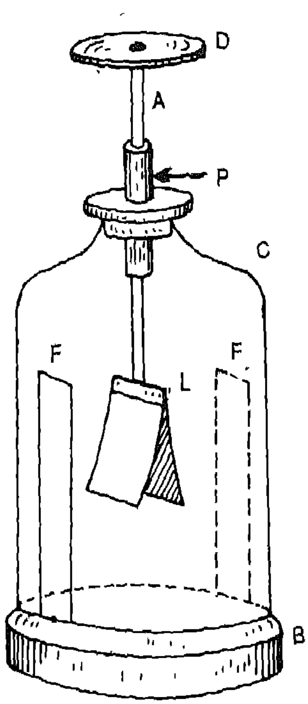


Fig. 1.14 *A sensitive gold leaf electroscope*

instead of gold leaves. Two tin foils F are fixed on opposite sides of the glass bell jar as shown in the figure. The bell jar is fixed on a wooden base B.

In order to test whether a given body is charged or not, the body (say a glass rod, ebonite rod, etc.) is brought near the electroscope and made to touch the metal disc D of the electroscope. Make this contact so that as large an area of the body as possible comes in contact with the metal disc D. If the body is charged, you will notice that the leaves L diverge. With this electroscope, you can detect a charge on a body, you can also show that the two bodies (such as glass rod and a silk cloth) involved in the process of rubbing acquire opposite charge.

TOPIC II. FORCE BETWEEN TWO CHARGES (COULOMB'S LAW)

1.12 (Experiment): To study the variation of force between two charged spheres with distance separating them.

Apparatus A simple apparatus to study the variation of the force between two charged spheres with distance separating them is shown in Fig. 1.15a. There are two spherical pith balls

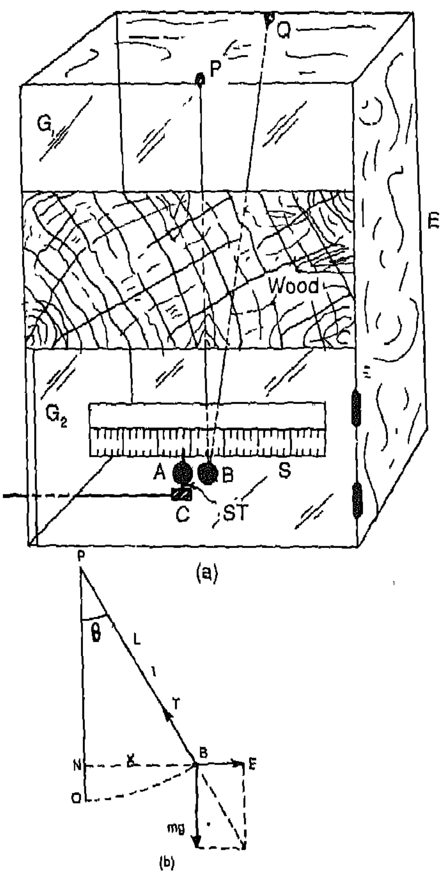


Fig 1.15 *Apparatus for the study of Coulomb's law*

A and B coated with conducting ink. One of the pith balls is suspended by two fine nylon threads PB and QB from the top of the box E The pith ball B is free to make small movement along a line parallel to the scale S made on the lower glass window G_2. This line is perpendicular to PQ and PB. Another pith ball A is mounted on a cork C with a match stick ST. This pith ball can be brought nearer to or taken away from the pith ball B, enabling one to vary the distance between A and B.

Procedure: Note the rest position of B on the scale. Let it be '*a*'. Keep the line of sight, while taking this reading, perpendicular to the scale so that you see the two threads coincident. Note the reading '*a*' on the scale with the help of the threads. Note the position of A on the scale likewise, with the help of pointed upper end of the match stick. Let this reading be '*c*' Rub a plastic strip with a woollen cloth and charge it. Insert this plastic strip in the box E and touch both the pith balls A and B. In so doing, you transfer some charge to A and some to B. Both A and B are charged. As soon as they acquire an electric charge, the suspended pith ball B gets displaced from its original position '*a*' due to repulsion by ball A Note the new position '*b*' From these readings, one can get an estimate of the force between the two charged spheres A and B Repeat the experiment for various positions of A, without altering the charges on the two balls.

$x = b-a$ is a measure of the force between the two charged pith balls. When the pith ball is not charged, it hangs vertically down because of the gravitational force mg and occupies the position '*a*' on the scale. Because of the force of repulsion between the two charges A and B, the suspended pith ball swings and occupies the position '*b*' on the scale. Now there are three forces acting on B. Force mg due to gravity vertically down, force F, a force of repulsion between A and B and tension T along BP (Fig. 1.15b). The suspended spherical ball B has swung through an angle θ In equilibrium, we have

$$\tan\theta = \frac{F}{mg}$$

$$\text{or} \quad \frac{x}{L\cos\theta} = \frac{F}{mg}$$

If θ is very small, then

$$mg\,\frac{x}{L} = F$$

m, L are constants and therefore

$$F \propto x$$

Thus we find that the displacement x is a measure of the force F.

With the above set of readings, plot variation of x with $\frac{1}{d^2}$. You will find that F varies inversely as the square of the distance d.

Thus two spherical charges repel each other with a force varying inversely as the square of the distance separating them.

For obtaining accurate and reliable results, work on dry day. Also see that there are no air currents in the wooden box. You can dry the air inside the box by hot air drier Then wait for about 15 minutes so that temperature in the entire space inside the box becomes uniform. Then it will not cause any air current inside the box.

Note: The above experiment makes a good classroom demonstration with following alterations. The scale in window G_2 is a strip of transluscent mm graph paper. The back of the box should also be of clear glass, so that a 60 watt bulb placed about 50 cm away behind the box casts shadows of both the balls on the scale. Figure 1.16 shows a view of the apparatus as seen from the top. You may replace the ball mounted on the ebonite/plastic rod by a larger ball A, about 5 to 7 times in diameter compared to the ball B Surface of A is also made conducting before mounting it on the rod.

Observations. Position of suspended ball when uncharged, a, = _______ cm

S.No	Position 'c' of the charged ball A (cm)	Displaced position 'b' of charged ball B (cm)	Displacement x of ball B $x = b\ a$ (cm)	distance d between A and B $d = b\text{-}c$ (cm)	$1/d^2$

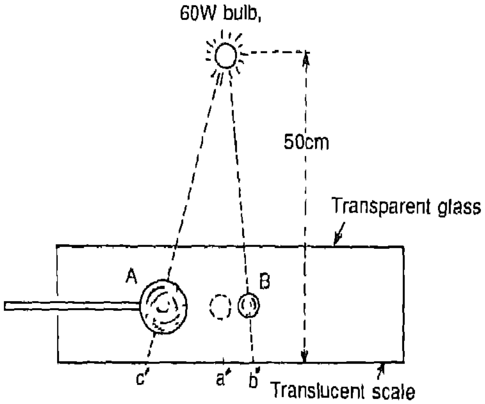


Fig. 1.16 *Top view of the Coulomb's law appar tus modified for classroom demonstration*

Then small ball becomes the test charge with the help of which you can demonstrate the characteristics of the electric field produced by charged ball A.

1.13 (Activity): To make a low cost torsion balance and study the variation of force between two spherical charges as a function of the distance separating them.

You can study the variation of force between two charged spherical conductors as a function of the distance separating them with a torsion balance commercially available, which has been described in your text. It is possible to make a low cost torsion balance for yourself.

Take a wide mouthed glass jar A of about 5 litre capacity and support a long unspun nylon thread B from top (Fig.1.17). At the top, the thread passes through a narrow gauge glass bushing on which rests a fine straight thin rod C which can be rotated round the vertical axis. Its position can be marked on the circular scale D. Make a circular scale S along the circumference of the glass jar. At the lower end of the nylon thread attach a thin capillary glass tube

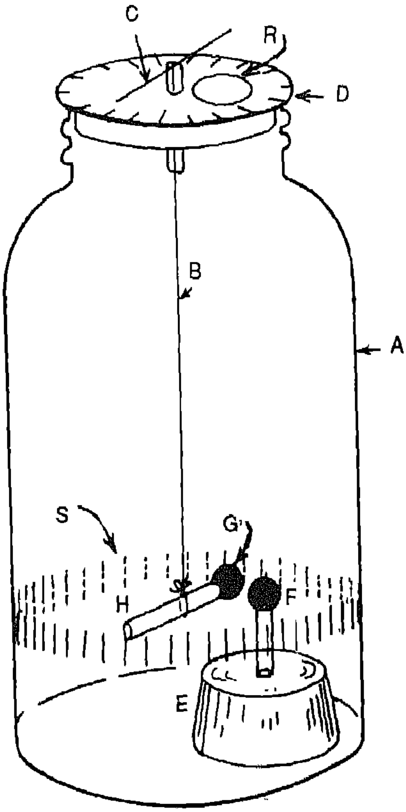


Fig 1.17 *Improvised torsion balance made in a 5 litre jar.*

GH Attach a coated pith ball G at one end of this capillary tube as shown Suspend the capillary GH so that it is horizontal GH should be at the same level as scale S.

Take a cork E of suitable size and fix into it with a thin glass rod another coated pith ball F. Adjust the height of F such that F and G are at the same level

Figure 1.18 shows a top view of the two pith balls and circular scale S You can look along

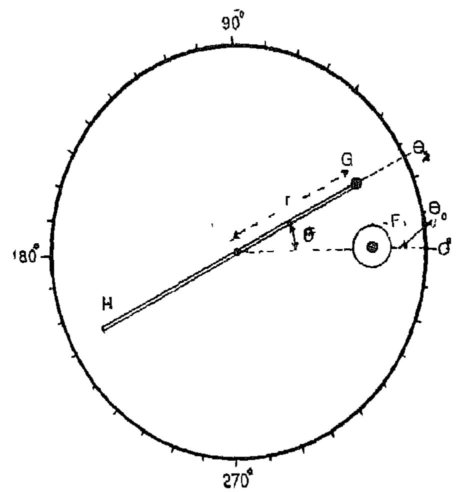


Fig 1 18 *Top view of the torsion balance in 5 litre jar. (The 360° protractor and indicator at the top of the jar are not shown)*

the rod GH and thus note the scale reading at which axis of the rod passes, i e the angular position θ_1, of the pith ball G on the scale S. Similarly, by looking along the line joining pith ball F and nylon thread, you can find the angular position of ball F on scale S.

Now introduce a charged ebonite rod into the jar through the hole in the top circular D. Touch the balls F and G by the rod and take it out. Due to force of repulsion between them, the separation between them increases. Note the new angular position of the suspended ball G and thus find its deflection $(\theta_2-\theta_1)$. Torsion ϕ in the Figure is thus equal to $(\theta_2-\theta_1)$ for angular separation θ between the balls equal to $(\theta_2-\theta_0)$.

Next, turn the indicator of the circular scale D by say, 15° clockwise (in figure 1.18). As the nylon thread is suspended by this indicator, the separation between the balls decreases. Note the new position θ_3 of ball F. Then torsion ϕ in the fibre is equal to $(\theta_3-\theta_1+15°)$ for the angular separation θ between the balls equal to $(\theta_3-\theta_0)$ In this manner, bring the balls closer and closer and note the increasing force of repulsion.

Instead of a qualitative experiment as described above, you can also make a quantitative study of Coulomb's Law by this apparatus, though the results may have large error. Keep the pith ball F on the cork at same distance r from the centre, as the suspended ball G This may be checked by rotating the indicator on the scale D (before charging the balls) so that the two balls come in contact Thereafter, note the position, θ_0 of the ball F and do not disturb it throughout the experiment. Then for an angular separation, θ, distance d between the balls is

$$d = 2r \sin \frac{\theta}{2}$$

If torsion constant of the nylon fibre is τ and torsion in it is φ (where value is $\theta_2 - \theta_1$, in first reading, $\theta_3-\theta_1+15°$ in second reading, and so on) then force of repulsion between the balls for angular separation θ is:

$$\text{force of repulsion} = \tau\, \phi/(r \cos \frac{\theta}{2})$$

Since τ and r are constants of the apparatus, d is proportional to $\sin \frac{\theta}{2}$

and force of repulsion is proportional to $\phi/\cos \frac{\theta}{2}$

Hence, according to Coulomb's law, you would expect a graph between $\phi/\cos \frac{\theta}{2}$ versus $(\sin \theta/2)^{-2}$ to be a straight line.

1.14 (Activity): To study the principle of superposition of electric fields.

Take a charged pith ball and suspend it with an insulating thread. Note the initial vertical position C of the pith ball. Make sure that there are no other charges around the pith ball. Now take a sphere (A) fixed on an insulated stand and charge it with the same kind of charge as on the pith ball. Place this charged sphere at position A near the pith ball. The pith ball would experience a force due to the charged sphere and get displaced to position X. The displacement CX is a measure of the force of repulsion at distance AX in the direction CX (Fig. 1.19). Next, remove the charged sphere

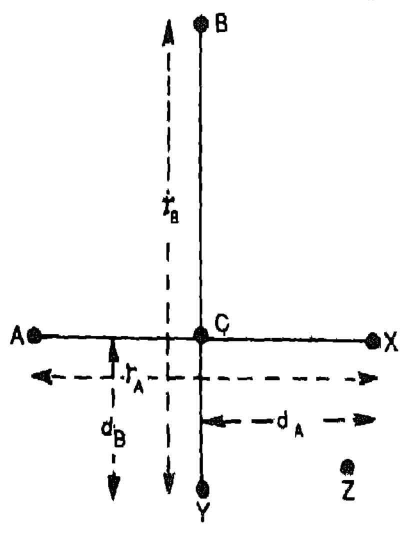


Fig. 1.19

from position A Bring another similarly charged sphere B fixed on an insulating stand and place it at a point B such that the lines AC and BC are at right angles to each other Note the position Y to which the pith ball C moves under the influence of the force due to charge on sphere B CY is now the measure of the force of repulsion between charges on pith ball C and the sphere B. Now put both the charged spheres simultaneously in their respective positions at point A and B. The pith ball will now simultaneously experience two forces viz., one due to A and another due to B and will get displaced to a new position z. With these observations, verify that the field due to the sphere A at z and field due to sphere B at z add vectorially. Take care that you have to take the two fields for position z of the ball C. Electric fields produced by a number of charges at a point add vectorially.

TOPIC III· ELECTROSTATIC INDUCTION

1.15 (Demonstration): To demonstrate that a charge can be induced in a body under the influence of an electric field due to another charged body.

Take two metal rods AB and CD, place them on two glass beakers E and F so that the rods touch each other as shown in figure 1.20 (a). Bring a charged plastic strip close to the end D of a metal rod. The plastic strip is negatively charged. It produces an electric field in such a way that the relatively free electrons in the metal rods are repelled away. Thus there is a paucity of electrons at the end D of the metal rod and excess of electrons at the end A of the other metal rod. Now separate the glass beakers so that the metal rods do not touch each other (Fig. 1.20.b). The plastic strip is now removed. The excess negative charge on the rod

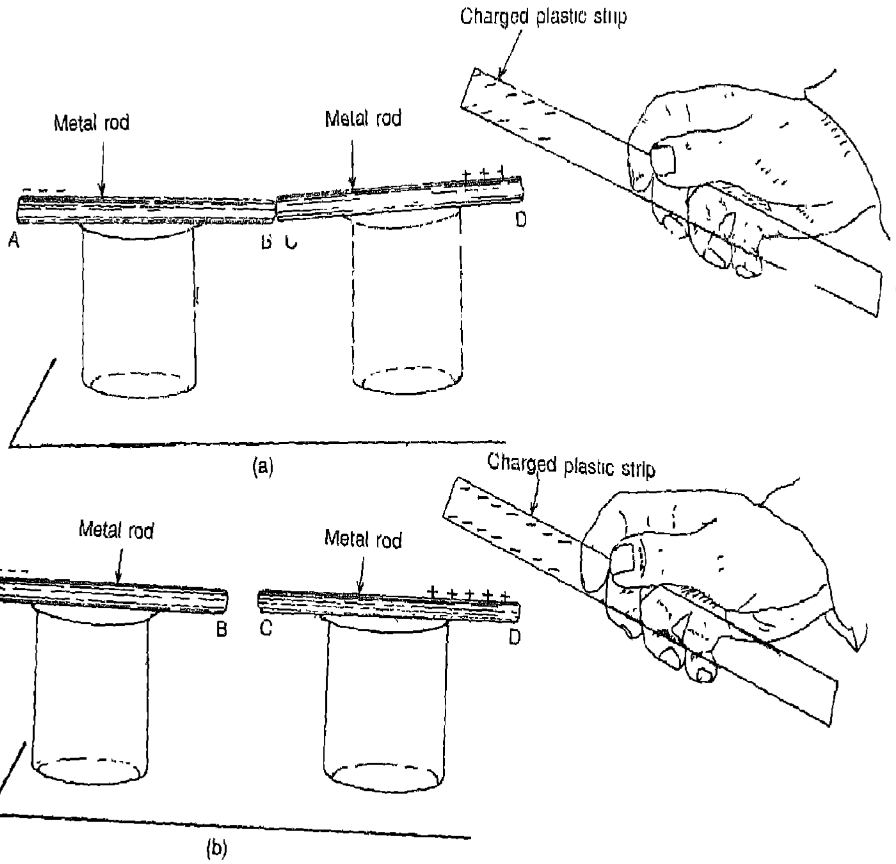


Fig. 1.20 Charging two metal rods by induction

AB now gets distributed all along the rod. Similarly, the positive charge on the other rod gets distributed along CD. Test the charge on the two metal rods and verify that they are oppositely charged. The charge on the plastic strip is called the inducing charge and the charge on the metal rods is called the induced charge.

Questions: 1. If positively charged ebonite rod is brought near the end D instead of a negatively charged plastic strip in the above experiment, will you be able to charge the two metal rods? What will be the charge on the rod AB and on

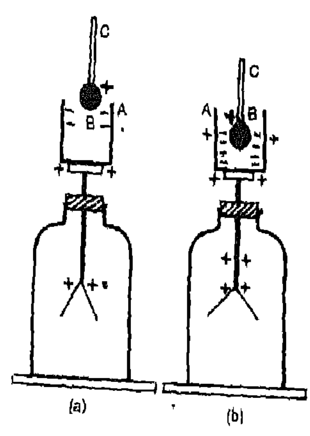


Fig. 1.21 (a, b)

the rod CD?

2. Do you think that the charge on the AB is equal and opposite to the charge on the rod CD?

3. Can you guess what will be the relationship between the induced charge and the inducing charge?

1.16 (Demonstration): To demonstrate that the induced positive charge and the corresponding induced negative charge on a conductor due to the field of a charged body are equal and opposite.

Take a gold leaf electroscope and place a metal can A on the disc of an electroscope as shown in the Figure 1.21. Take a metal ball B with a long insulating handle C Charge the metal ball positively by rubbing it against a silk cloth. With the insulating handle, lower the metal ball inside the can A (Fig 1.21a). What do you observe? You will see that the leaves of the electroscope diverge showing that they are charged. The metal ball induces a negative charge on the inner surface of the metal can A and positive charge on the outer surface of the can, the disc of the electroscope and the leaves of the electroscope.

Remove the ball from the can. You will observe that the induced negative charge on the inner surrface of the can, neutralizes the positive charge on the outersurface, disc of the electroscope and leaves of the electroscope and consequently the leaves collapse. There is now no net charge on the leaves.

Lower the metal ball in the can more and more, you will observe that the leaves diverge more (Fig. 1.21b) In this case too, on removing the ball from the can, you observe that the induced negative and positive charges neutralise each other.

See what happens when the metal ball touches the inner surface of the can, after having lowered it deep Explain your observation

1.17 (Demonstration): A charged body attracts an uncharged body due to the production of induced charges on the uncharged body in the field of the charged body

Take a pith ball A about 5 mm in diameter. Coat its surface with a conducting ink and suspend it as shown in the fig. 1.22. Bring a charged metal rod B supported on an insulating stand. You will notice that the pith ball A is attracted to the metal rod.

The metal rod B is charged negatively. It induces positive charge on the hemispherical surface close to the metal rod and a negative charge on the hemispherical surface away from the rod as shown in the figure. Since the distance between the positive charge on the surface of the pith ball and the metal rod is smaller than the distance between the negative charge on the surface of the pith ball and the metal rod, there is net attraction between the metal rod and the pith ball.

In much the same way, a charged body attracts pieces of paper.

1.18. (Demonstration): To demonstrate that the attraction between a charged and an uncharged body is due to the charges induced on the uncharged body.

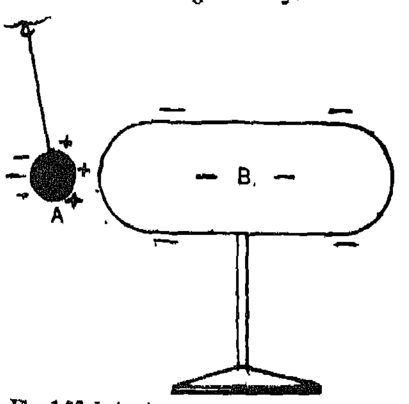


Fig. 1.22 *Induction precedes attraction*

Take a large conical metallic body A, mounted on an insulating stand. Suspend a pith ball coated with conducting ink about 3 cm away from the sharp end of the metallic conical body A as shown in the figure 1.23. Place a metallic sheet C another 3 cm away from the suspended pith ball. The metallic sheet is earthed. Charge the conical body by rubbing it with a silk cloth. The pith ball B is attracted to the conical metallic charged body because of the charges induced on the spherical pith ball as in the earlier demonstration. Because of attraction, the pith ball swings and touches the metallic charged body. As soon as the pith ball touches the conical body, the pith ball acquires positive charge from the conical body by the process of conduction. Since the pith ball has now acquired similar charge as that on the metallic body there is repulsion between the pith ball and the conical body. As a consequence, the pith ball swings now on the other side and touches the earthed plate C. As soon as the pith ball touches the plate C, the charge on the pith ball leaks to the earth and the pith ball becomes uncharged. Consequently it tries to go back to its central position. As it leaves the earthed plate C, the pith ball acquires induced negative charges which causes attraction between the pith ball and the conical body. The whole process repeats and it is a pleasure to see the oscillations of the pith ball.

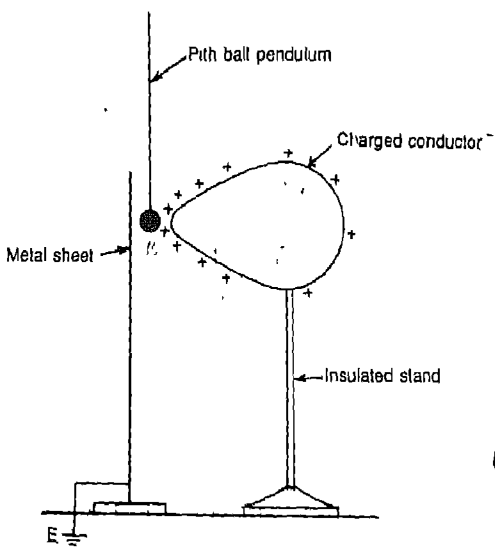


Fig. 1.23

1.19 (Demonstration): To demonstrate the force of attraction between a charged comb and an uncharged umbrella.

Hang a large umbrella AB horizontally by a piece of twine (a strong thread). Comb your dry hair with a comb so that it gets charged. Bring the charged comb near one end of the suspended umbrella (Fig. 1.24). The comb is negatively charged. It induces a positive charge on the end B of the umbrella and a negative charge on the remote end A of the umbrella. Since the negative charge on the comb is nearer the positively charged end of the umbrella than the neg-

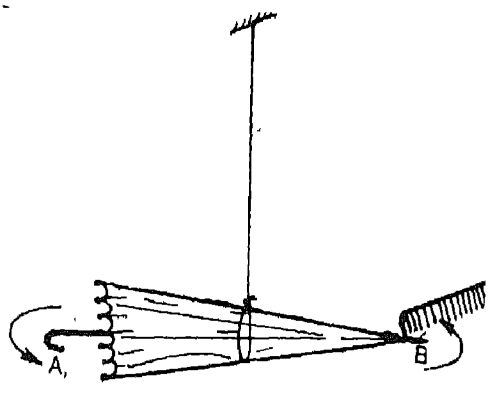


Fig. 1.24

atively charged end, there is a force of attraction between the end B and the comb. This force of attraction causes the umbrella to rotate.

1.20 (Activity): Attraction between a charged and an uncharged body.

(a) Balance a metre scale on the inverted surface of a watch glass (Fig. 1.25a) Bring a charged plastic pen near one end of the scale and observe what happens

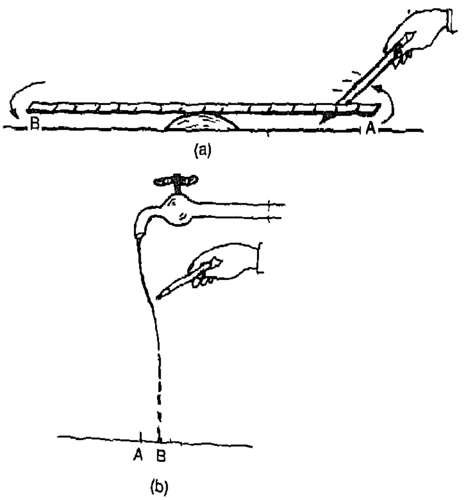


Fig. 1.25 (a, b)

(b) Let a thin stream of water flow out of a tap about 100 to 120 cm above the ground (Fig. 1.25b). Bring a charged ball pen with a plastic body near the water stream and observe what happens

1.21 (Demonstration): To charge a body by induction.

Take a gold leaf electroscope. Place a metallic can on the disc of electroscope. The can has no charge and the leaves of the electroscope are parallel to each other. Insert a charged metallic

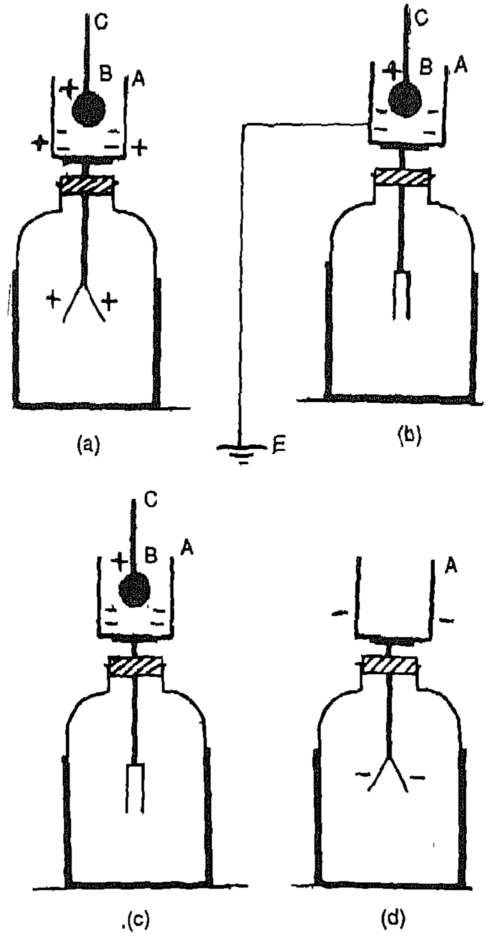


Fig. 1.26 *Charging a conductor by induction*

ball in the can by holding it with an insulating rod C. Do not touch the surface of the can. The charged metallic ball induces a negative charge on the inner surface of the can and a positive charge on the outer surface of the can and the leaves of the electroscope. The leaves diverge (Fig. 1.26a). Now touch the outer surface of the can and thus earth it (Fig. 1.26b). Electrons flow from the earth to the outer surface of the can and the leaves of the electroscope to neutralise the positive charge The leaves will collapse

because they have lost their charge Remove the earth connection (Fig 1 26c) and, thereafter, raise the charged metal ball and take it out of the can (Fig 1 26d) You will find that the leaves diverge indicating a charge on the can. The excess electrons which were held by attraction of ball B on the inner surface of the can, now get distributed giving the can and the leaves a negative charge Thus, through this process you can charge a body by the process of induction. Note that the charge thus induced is always opposite to the inducing charge.

The induced positive charge which got neutralised on earthing the can is called *free charge* The induced negative charge held by attraction of ball A on inner surface of the can is called *bound charge*.

1.22 (Demonstration): Charging a body by an electrophorus.

An electrophorus is schematically shown in Fig. 1 27. It consists of a thick (about 2 mm) disc

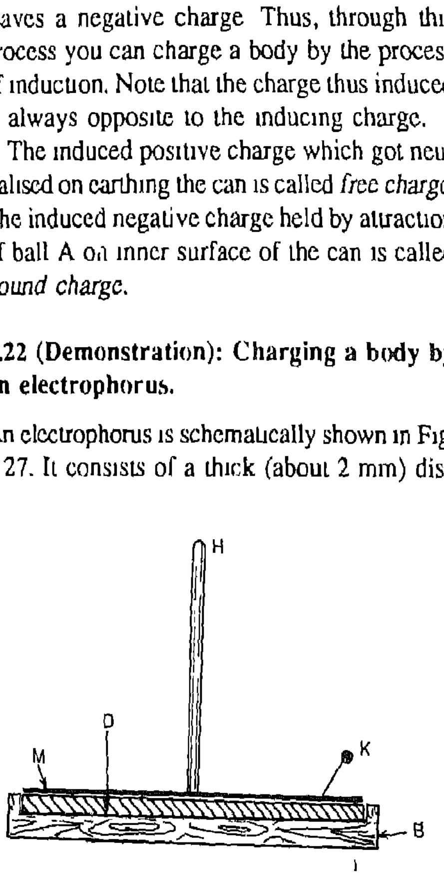


Fig. 1.27 *An electrophorus*

D (radius about 7.5 cm) made of ebonite or polythene fixed in the wooden base B. There is a metal disc M of a diameter slightly less than the diameter of the ebonite disc. This metal disc is fitted with an insulating handle H, so that you can hold it without the charge on the metal disc leaking away The metal disc is fitted with a small metal knob K.

Rub the ebonite disc with a woollen cloth to charge it negatively. Now place the metal disc on the top of the ebonite disc. The negative charge on the ebonite disc will repel free electrons in the metal disc to create a deficiency of electrons on the surface of the metal disc touching the ebonite disc. It correspondingly produces extra electrons or negative charge on the upper surface of the metal disc. Now earth the upper surface of the metal disc. In so doing, the negative charge on the upper surface of the metal disc leaks to the earth. Remove the earth connection. Now remove the metal disc with the insulating handle Touch the knob of the metal disc to a large metal sphere connected to the disc of a gold leaf electroscope. You will see that the leaves diverge. The electroscope and metal sphere have been charged by conduction

Place the metal disc M, again on the ebonite disc D. Touch the upper surface to earth it, remove the earth connection, lift the metal disc and touch the charged metal sphere and the electroscope with its knob K You will see that the leaves diverge further. You have now charged it more. You can repeat the process and successively charge the sphere connected to electroscope

The charging of a body by using an electrophorus can be quite spectacular in the following way.

Take an insulated stool and request your friend to stand on it. Charge your friend, as you charged the metal sphere earlier, successively. You will find on a dry day, after about one hundred chargings, your friend's hair standing up.

Note: From the above demonstration, it appears that you can charge a body (metal sphere or a student) with an infinite amount of charge.

This is not true. What essentially happens is you are transferring the negative charge (electrons) to earth from the metal sphere or the student.

You have seen that when you earth the top surface of the metal disc, you allow the electrons from the top surface to flow to earth. After removing earth connection, the metal disc has deficiency of electrons and thus gets positive charge. When you touch the electroscope with the knob K of the metal disc, electrons flow from the metal sphere or the student to the metal disc. In the process, electrons are transferred from the metal sphere/student to the earth.

1.23 (Activity): To make an improvised electrophorus.

Take 5 cm thick thermocole sheet of about 25 cm x 25 cm in size. The smoother the surface, the better it is. You may choose a suitable one from several pieces. To a plane aluminium sheet (22 SWG) of about 20 cm x 20 cm fix a wax candle, at its centre. Rub the thermocole sheet with a smooth silk cloth or even or ordinary paper and charge it. Place the aluminium disc on the top of the thermocole sheet. Touch the upper surface of aluminium sheet to earth it. Remove the earth connection. Lift the aluminium disc with the wax candle You have charged the aluminium disc. This simple electrophorous serves admirably well to charge a body. You can 'see' the charge on the aluminium disc. As you bring your knuckle close enough, a spark can be seen to jump from the aluminium disc to your finger.

1.24 (Demonstration): To demonstrate the phenomenon of electrostatic shielding.

(a) Take a gold leaf electroscope and charge it negatively. Bring a negatively charged ebonite rod near the disc of electroscope. The ebonite rod is charged negatively. The ebonite rod induces a positive charge on the disc of the electroscope and negative charge on the leaves of the electroscope As a consequence the leaves diverge more and more as you bring the ebonite rod closer to the disc of the electroscope You can thus influence the charge on the electroscope leaves by bringing charged bodies near the disc D of the electroscope. Now lower the can C gradually to contain the disc D (Fig 1.28). Earth the can. Now bring the charged

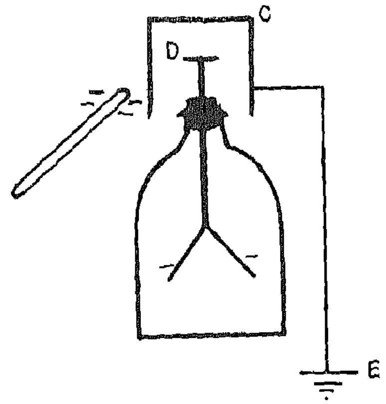


Fig. 1.28 *The earthed can C sheids the disc D from the field of ebonite rod*

ebonite rod near the disc of the electroscope as in the previous case, you now see that the presence of the charged ebonite rod hardly affects the leaves of the electroscope. This shielding is called electrostatic shielding.

(b) These days you get electronic regulators for the electric fans. These regulators can also be used to dim the light from the bulbs in the room appropriately. Take a small transistor radio receiver. When the fan is off, tune the transistor and bring it near the regulator. You will see no change in the quality of the music. Now switch on the fan and adjust the electronic regulator. If transistor is close to the regulator you will hear considerable disturbance in the music Now wrap a thin copper foil or aluminium foil round the regulator and earth it. You will notice

that the quality of music has considerably improved. This has happened because the metal foil shields the transistor from the electrical disturbances generated in the regulator.

You will thus see that a sensitive gold leaf

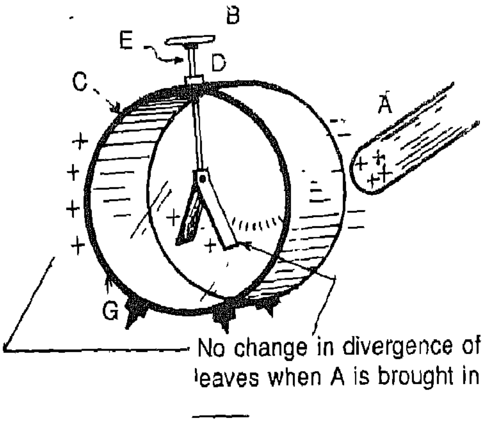


Fig. 1.29 *A shielded electroscope*

electroscope which is supposed to measure charge accurately needs to be shielded properly so that 'the neighbouring charges do not affect the leaves. In order to shield the electroscope

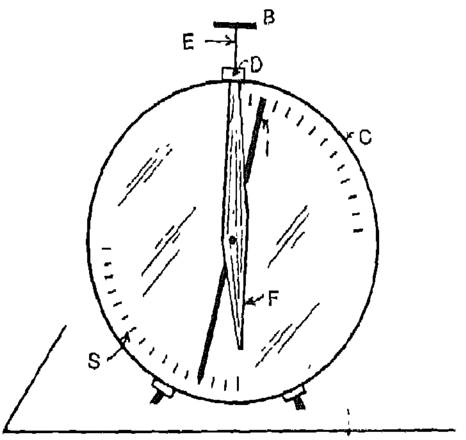


Fig. 1.30 *A sensitive shielded electroscope with scale.*

properly, it is made in a metal can C (Fig. 1.29). In order to be able to see the leaves, the lid of the can is replaced by a circular glass sheet G. Thus there is no change in the divergence of leaves if an undesirable charge A is brought in at the sides or at the back of the electroscope. The stem E holding the leaves may be insulated from the earthed can by an insulated stopper D.

In order to make the electroscope more sensitive and capable of measuring the charge, the moving element is a light straw, I, with conducting surface instead of two metal leaves (Fig. 1.30). A pin passes through the straw just above its C G. and is held in two holes in the frame, F The straw is normally vertical when not charged. When it is charged, it repels the frame and rotates clockwise. The angle through which it rotates depends on (and therefore indicates) the amount of charge on the electroscope. Angle through which the indicator (i.e. straw) rotates can be measured on a scale S behind it.

TOPIC IV ELECTRIC POTENTIAL

1.25 (Demonstration): To demonstrate the concept of potential.

Take a pith ball of radius 2 or 3 mm coated with conducting ink. Suspend it with a silk fibre about 10 cm long in a small stand. Do it in such a way that the position of the pith ball can be changed by shifting the stand. Charge the pith ball positively. Take a metal sphere of 5 cm radius on an insulating stand. Charge it positively. Suspend charged pith ball from positions A, B and C and note down the deflection in each case (Fig. 1.31) For this purpose a dry

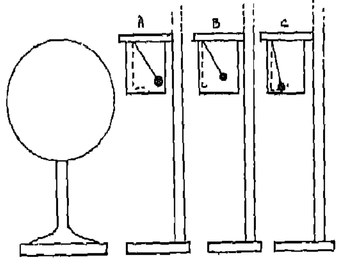


Fig. 1.31

paper, with a circular scale marked on it, may be fixed vertically behind the pith ball pendulum, but not touching it. The deflection increases as the pith ball comes nearer the charged conductor. In each of the cases, if you want to bring back the pith ball to its equilibrium vertical position, you will have to do work. This work is stored in the charged conductor and pith ball as electrostatic energy. If the pith ball were free to move without constraint of the silk fibre, then because of electrostatic repulsion, it would have moved away from the charged conductor indefinitely to be at an indefinite distance from the conductor The work done in bringing the charged pith ball from infinite distance to a point at a distance r from the conductor will increase as r decreases It can be shown by calculations based on Coulomb's law that the electrostatic mutual potential energy varies inversely as the distance.

1.26 (Activity): Potential of charged body which moves against electrical force acting on it.

You have seen earlier that if you bring the knucle of your finger close enough to a charged conductor, a spark is seen to pass from the charged sphere to the finger. The field between your knucle (connected to earth) and the charged conductor becomes so large at small distances that air in between your finger and the conductor becomes conducting and charge flows from the conductor to the knucle.

Charge the disc of an electrophorus by rubbing its ebonite disc rather briskly so as to produce as large a charge as possible. Place the metal disc on the ebonite disc, touch it by a finger and remove the finger. Raise the metal plate. You have charged the metal plate with a charge opposite to the charge on the ebonite disc. When the metal plate is close to the ebonite disc, the spark does not pass if you bring a knucle of your finger close to the metal disc Put the metal disc on ebonite disc and repeat the process of charging. Now raise the metal disc from the ebonite disc by about 40 cm. Bring the knucle of your finger close to the edge of the metal disc. You will now see a spark to jump from the metal disc to your finger. In this case, you have lifted the disc against the force of electrostatic attraction between the charge on the ebonite disc and opposite charge on the metal plate. This work is stored in the pair of plates as electrostatic energy. This energy per unit charge on the metal plate is the potential due to the charge on the ebonite disc.

1.27 (Demonstration) : To demonstrate that the gold leaf electroscope can be used to measure potential difference.

Take a gold leaf electroscope shown in Fig. 1.14. The two foils F and the base B are earthed. This electroscope can be used to measure the potential of the metal plate of the previous experiment.

Charge the ebonite disc of the electrophorus by rubbing it with a silk cloth. Place the metal disc on top of the ebonite disc of electrophorus. Touch the top surface of the metal disc and thus earth it. Now connect the knob of the metal disc B to the disc of an electroscope. The leaves of electroscope remain collapsed (Fig. 1.32a). Remove the earth connection (Fig. 1.32b). Then lift the disc. The divergence of the leaves increase as the metal disc of the electrophorus is lifted up (Fig. 1.32c & d). You have seen in the earlier experiment, the potential of the metal disc relative to the ebonite disc increases as you increase the separation between them. As the potential of the metal disc increases, so does the divergence of the leaves. By connecting the metal disc of the electrophorus to the metal disc of the electroscope, you bring the electroscope disc and the leaves to the same potential as that

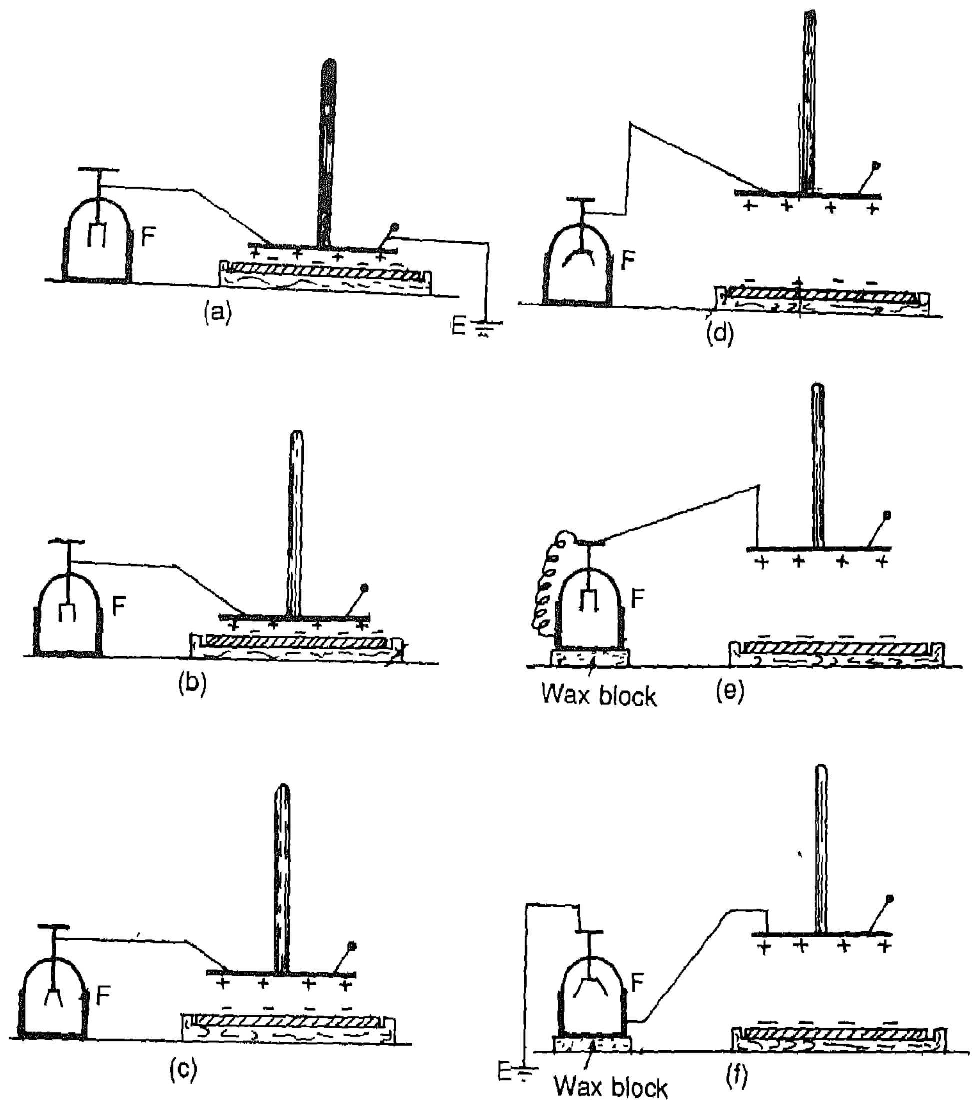


Fig. 1.32 (a, b, c, d, e, f)

of the metal disc of the electrophorus.

Connect the disc of the electroscope to the foils F of the electroscope and place it on a block of wax so that it is insulated from earth (Fig. 1.32c). Repeat the experiment mentioned above, you will find that the leaves of the electroscope do not diverge even if you lift the metal disc of the electrophorus above the ebonite disc and thus increase its potential. There is no divergence of the leaves because the gold

leaves and foils F are at the same potential.

It may thus be seen that the divergence of the leaves is essentially due to the potential difference between the leaves (also the disc of the electroscope) and the metal foils F

Notes: 1. You can also use the gold leaf electroscope to measure potential difference, if the disc of the electroscope is earthed and the body whose potential is to be measured is connected to the foils F (Fig. 1.32f). In this manner you create the potential difference between foils F and the leaves which is equal to potential difference between earth and that body.

2. If you have a D.C. power supply (0 to 500 volts which is used for Millikan's experiment) and a scale to measure the divergence of the leaves, you can calibrate the scale directly to measure the potential difference between the foils F and the leaves of the electroscope in volts.

TOPIC V: CAPACITANCE OF A CONDUCTOR

1.28 (Demonstration): To demonstrate that the potential to which an insulated spherical conductor can be raised by giving a certain amount of charge depends upon the size of the conductor.

Take three insulated conducting spheres A, B and C. A and B are of the same radius, whereas C has a radius twice that of A and B. Place the conductors A and B so that the conductor A touches the conductor B as shown in the Figure 1.33a Bring a negatively charged plastic strip near the conductor A This plastic strip will induce a positive charge on A and a negative charge on B Separate the two conductors A and B while the plastic strip is still near the conductor A. Remove the plastic strip Now A and B have equal but opposite charges.

Take a gold leaf electroscope with foils F connected to earth. Touch the disc of an electroscope (which has a scale to measure divergence of leaves or rotations of its indicator straw) with conductor A The leaves of the electroscope will diverge. Note down the divergence. Now remove A. Earth the disc of the

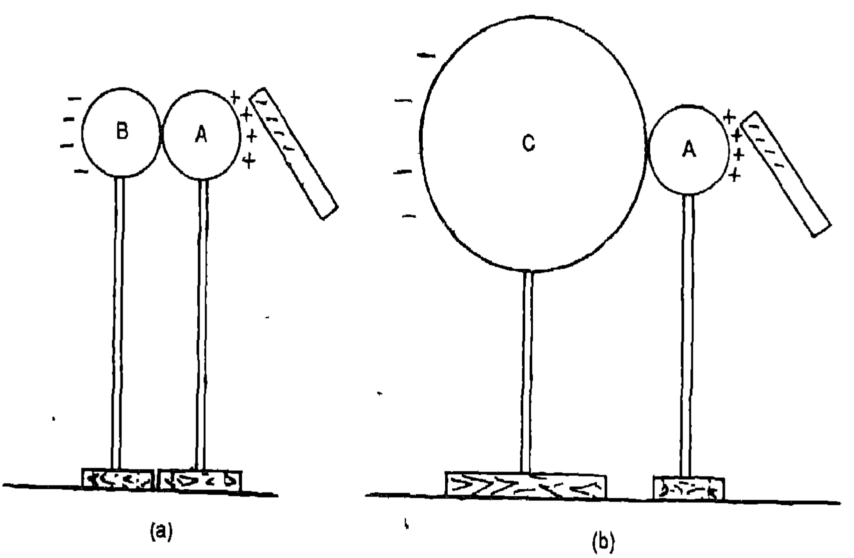


Fig. 1.33 *On being given the same amount of charge, the larger sphere acquires lower potential*

electroscope The leaves will collapse Now touch the disc of the electroscope with the conductor B. You will see the leaves diverge again You will also notice that the divergence of the leaves now is the same as the divergence of the leaves observed when A touched the electroscope. This shows that both A and B have been raised to the same potential because of equal charge on them (The potential of A is positive whereas that of B is negative) Discharge the electroscope

Now keep the conductors A and C in contact (Fig 1.33b) Bring as before a negatively charged plastic strip near the conductor A A will acquire positive charge and C will acquire equal but negative charge by induction Separate the two conductors A and C Measure the potential of A and C with a gold leaf electroscope. You will find that the divergence of the leaves of the electroscope is less when C is connected to the electroscope than the divergence of the leaves when A is connected to the electroscope. This shows that C has been raised to a numerically lower potential than that of A, (A has positive potential, C will have negative potential because charge on A is positive whereas the charge on C is negative) you can take a number of insulated metallic conductors of varying shape and size (sphere of different radius, cylinders of varying radius) and note the potential to which they are raised by giving them the same charge. You will observe that the potential to which an insulated metallic conductor can be raised by giving a certain charge depends on the size and shape of the conductor.

1.29 (Demonstration): To demonstrate that the potential to which an insulated metallic conductor is raised depends upon the charge on the conductor.

Take an electrophorus described earlier. Take an insulated spherical conductor A which is charged successively with an electrophorus Take a gold leaf electroscope to measure the potential of the spherical conductor Keep it connected to the conductor. Note divergence of leaves each time you deliver some charge to conductor by the disc of electrophorus.

You will notice that the potential of the metallic conductor increases as you charge the conductor successively.

Indeed there is a linear relation between the charge on the conductor and the potential to which it is raised. The constant of proportionality, i.e. ratio of the charge on the conductor to the potential to which it is raised, is called the capacitance of the conductor.

Question You have seen in demonstration 1 29 that a bigger spherical conductor acquired a lower potential than that acquired by a smaller spherical conductor on giving them equal amount of charge Which of the conductors has a larger capacity?

1.30 (Demonstration): To demonstrate that the potential of a conductor depends not only on the charge acquired by it but also on the presence of other charged or uncharged conductors in the surroundings.

(a) Take a small spherical conductor on an insulating stand Connect it to an electroscope. Rub the metal sphere with a silk cloth. The sphere acquires a positive charge and, because of its capacitance, a certain potential. This potential is measured by the electroscope by the divergence of the leaves (Fig. 1.34a). Now bring another negatively charged body (say, a thick ebonite rod or vinylite strip rubbed by dry woollen cloth). As you bring this negatively charged body near the spherical conductor, the leaves of the electroscope collapse (Fig. 1.34b). If you bring this negatively charged body very near the spherical conductor, the

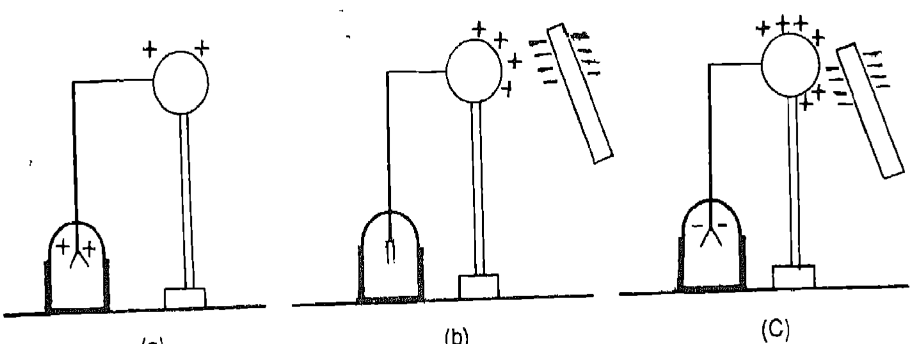


Fig. 1.34 (a, b, c)

leaves diverge again (Fig. 1.34c). Since electroscope measures the potential of the connected metallic spherical conductor, it is seen from the above demonstration that the potential of the spherical conductor can be changed by bringing another charged body close to it.

(b) Connect a metallic spherical conductor in an insulated stand to the disc of an electroscope Connect the disc to the earth and ensure that both the metallic spherical conductor and the electroscope are at earth potential. Remove the earth connection Bring a negatively charged vinylite strip near the spherical conductor You will find that the leaves of the electroscope diverge indicating that the metallic spherical conductor has acquired a potential.

Note: The above experiments can also be done by a positively charged strip and the metallic spherical conductor charged negatively or initially at earth potential. In fact, potential of a body whether its charge is positive or negative or zero, is affected by any other charge in its vicinity.

TOPIC VI CAPACITANCE OF A CAPACITOR

1.31 (Demonstration): To demonstrate that on bringing an earth connected conductor near a charged conductor, the potential of the charged conductor decreases and the capacity of the system (charged conductor and earthed conductor) increases.

Take two glass plates of roughly 30 cm x 30 cm. Paste aluminium foil on one of the flat surfaces of each glass plate. Let aluminium foil extend a little beyond one edge (Fig. 1.35) so that by folding it, one can make electrical connection with the help of a metal clip. You can charge the aluminium foil of one of the glass plates positively with an electrophorus. Place it on 4 wax blocks and then place 3 mm thick separator blocks of about 2 cm x 2 cm at four

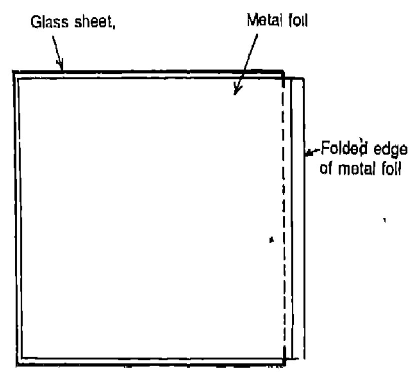


Fig. 1.35

corners. Place on top of these separators the second glass plate coated with aluminium foil. The aluminium foil coated faces should face each other (Fig 1 36). The upper plate has an

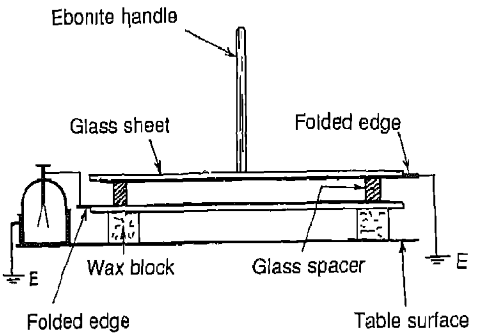


Fig. 1 36 *Improvised parallel plate capacitor Distance between plates can be varied by using different sets of glass spacers*

ebonite or plastic handle of suitable thickness (say a rod of length 20 cm and diameter 25 cm) fixed in the centre of glass side, for lifting it. As soon as you put the other glass plate on top of the first, the leaves of the electroscope collapse a bit. Now earth the aluminium foil on the upper glass plate. As you earth it, the leaves collapse significantly indicating that the potential of the charged aluminium foil has substantially decreased or the capacity of the system has increased. You will find that the capacity of the system increases as the separation between the two glass plates decreases.

1.32 (Demonstration): To demonstrate that the capacity of parallel plate capacitor depends upon the medium separating the two condenser plates.

Take an assembly of parallel plate capacitor consisting of two glass plates coated with aluminium foil on one of the faces of each of the plates and separated by separators. Charge one of the aluminium foils and earth the other and thus make a capacitors as described in demonstration 1.31. Measure the potential of the charged aluminium foil with a gold leaf electroscope. The separation between the two plates should be about 4mm. Now insert a 2mm thick plastic sheet in between the two glass plates. Observe the potential with the gold leaf electroscope on inserting the plastic sheet (Fig 1.37). You will notice that the deflection of the

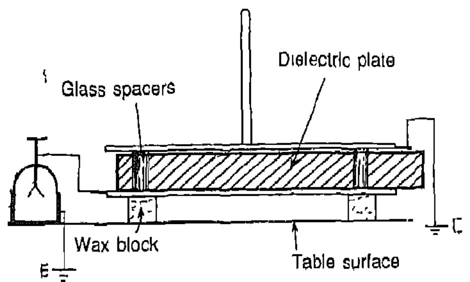


Fig 1.37 *A set-up to study the effect of dielectric plate on the capacitance of parallel plate capacitor*

gold leaves decreases on inserting the plastic sheets indicating that the capacity of the condenser has increased. Try inserting sheets of different materials such as glass, ebonite, etc in between the two glass plates of the condenser and observe the decrease in deflection of the gold leaf electroscope in each of the case. You will observe that the capacity of a parallel plate condenser depends upon the material separating the two capacitor plates.

DIELECTRIC CONSTANT OF AN INSULATOR

The ratio by which the capacitance of a capacitor increases when space between the two plates is completely filled by an insulating material instead of air (strictly speaking, instead of vacuum), is called the dielectric constant of that material In the above demonstration 1 32, since the insulator plates only partially fill the space between the two plates and there is lot of air space left, the increase in capacitance in each case is in a ratio less than the dielectric constant.

For electronic circuits there is always a need to have capacitors of small size having a specified capacitance and capable of withstanding a certain potential difference between the plates This is achieved by using insulating materials of high dielectric constant For some applications, however, the best material is not necessarily the one with highest dielectric constant There are other considerations too Mica, for instance, is among the best materials used for making standard capacitors, though, its dielectric constant is quite low (see table I in data section)

TOPIC VII. PRODUCTION OF HIGH POTENTIAL DIFFERENCE

1.33 (Demonstration/Activity): To demonstrate the production of high potential using a 9-volt battery.

Make a parallel plate condenser as in demonstration 1.31. Separate the two glass plates by a waxed tissue paper. (You can make a wax tissue paper by soaking the tissue paper in molten wax as described in Appendix 1). Connect the positive terminal of a 9 volt battery (6 dry cells connected in series in battery box) to the aluminium foil on the lower glass plate. Similarly connect the aluminium foil on the upper glass plate to the negative terminals of the battery (Fig. 1 38a). The potential difference between the two aluminium foils on opposite glass plate is now 9 volts.

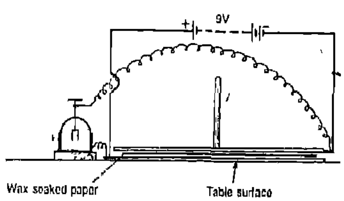


Fig. 1 38a

Connect the aluminium foil on the lower plate to the foils F of an electroscope, which are earthed and connect the aluminium foil on the upper plate to the disc of an electroscope. The electroscope in this arrangement measures the potential difference between the two aluminium foils. The potential difference between the two aluminium foils on opposite glass plate is 9 volts This is far too small for the electroscope to show appreciable deflection. In charging the condenser to a potential difference of 9 volt, you have transfered some charge to the upper plate.

Now disconnect the connection of the battery to the aluminium foil on the upper glass plate, hold the insulating handle of upper plate in hand and raise the upper glass plate slowly and observe what happens to the leaves of the electroscope You will find that the leaves diverge more and more as you lift the upper glass plate, indicating that now the potential difference between the two aluminium foils on opposite glass plates has increased

Note . 1. This experiment can also be (in fact, still better be) done by using a thin P V.C. sheet as the dielectric instead of wax soaked tissue paper, P.V.C. sheet may be taken from the common PVC bags used for packing materials.
2. A battery is normally a source of electric current A question may be asked that how is it that it provides electric charge to the capacitor plates. Certainly a steady current does not flow in the circuit, as the two plates are separated by an insulator However, a current flows for a short while, as can also be tested by inserting a very sensitive galvanometer (suspended coil type) in series with the battery. Since this current charges the plates, it infers that flow of electric charge constitutes an electric current
3. The mechanics of the passage of a pulse of current in the capacitor is as follows. The negative terminal of the battery supplies electrons to the upper plate. This negative charge produces equal amount of induced positive charge on the lower plate. Electrons in the lower plate are repelled to go back to the positive terminal of the battery. As the charge on the plates increases, the potential difference between the plates increases, till it becomes equal to that of the battery. When this happens, the current stops because p.d. between the plates and p.d. between battery terminals tend to flow currents

in opposite directions in the circuit (Fig 1.38b).
4. This demonstration can be done equally well by connecting lower plate of the capacitor to negative terminal of the battery.

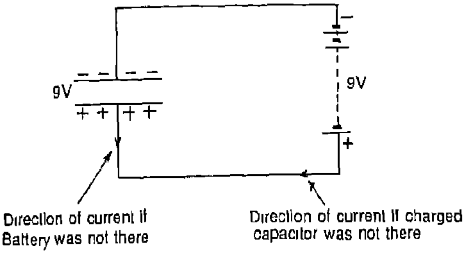


Fig 1.38

1.34 (Demonstration): To demonstrate a school-type Van-de-Graaff generator and charge it to a high potential.

Large Van-de-Graaff generators are used to produce potential difference upto 14 million volts for accelerating atomic particles for nuclear research programmes. If a simple Van-de-Graaff generator is available for demonstration in the classroom, its functioning may be demonstrated and its parts be explained. Fig. 1.39 shows the essential parts of a simple Van-de-Graaff generator.

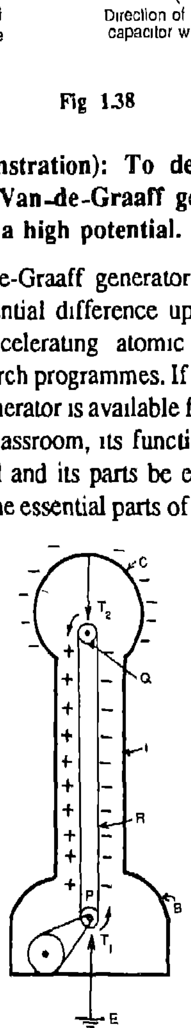


Fig. 1.39 *A simple Van-de-Graaff generator*

The base B is made of metal and is earth connected. A perspex roller P placed in it is driven by a small electric motor, thus moving a rubber belt, R_1 on it. A comb (a series of sharp metallic points) T_1, is placed at a few millimetres from the belt It is earth connected The belt runs inside a tall plastic pillar, I (which is a good insulator). On this pillar is supported the collecting sphere C Inside the sphere is fixed a polythene roller Q which is driven by the rubber belt. Another comb T_2 is fixed inside the sphere C and is kept at a few millimetre from the rubber belt.

Initially a positive charge is produced on the motor-driven perspex roller by friction between it and the rubber belt. This charge induces a negative charge on the earthed comb T_1 by drawing electrons from earth. As the electric field near sharp points is quite strong, air molecules are attracted towards them, get charged (negatively) and then thrown off towards the roller P. By this electric wind, negative charge from sharp points of T_1 is "sprayed" on the outside of the belt and carried upwards

The comb T_2 is connected on the inside of sphere C, when the negative charge on upward moving belt reaches opposite T ositive charge is induced in T_2 epulsion of electrons in T_2 with the belt. These electrons reach the sphere C and charge it negatively. An electric wind is set up between T_2 and belt which not only neutralises negative charge of the belt but also charges it positively, because polythene roller inside the belt gets negatively charged due to friction between rubber and polythene.

A large force of repulsion is set up between negative charge on the collecting sphere and negative charge on the upward moving belt. Similarly, a large force of attraction is set up between negative charge on collecting sphere and the positive charge on the downward

moving belt. The motor driving the roller, therefore, has to do work against these forces. This energy is stored in sphere C as the potential energy of negative charge on it

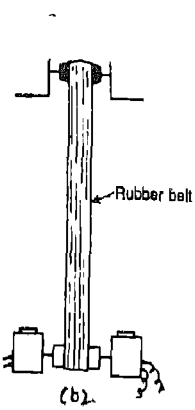
By putting polythene roller in B and perspex rollers in C, this generator will collect positive charge on the sphere C

An interesting activity to demonstrate the high potential generated by the machine is to put a wig on the sphere C. Within a few seconds after the motor is switched on, potential of sphere C becomes so high that the hair stand up. Do not try to take spark from the sphere on the knuckle of your finger, as it can be dangerous (see table 2 in data section).

1.35 (Activity): To make a simple Van-de-Graaff generator.

A simple Van-de-Graaff generator can be made as a students' project at a very low cost and with relative ease. Use a circular aluminium baking pan for the base (Fig. 1.40a) It is put upside down. In the centre of the bottom of the pan, which is now the up-side, cut a square hole 7.5 cm x 7.5 cm.

Over this opening fix a tall plastic cylinder whose inside diameter is at least equal to diagonal of the square hole, with the help of 8 aluminium angles of about 12 mm x 12 mm. The



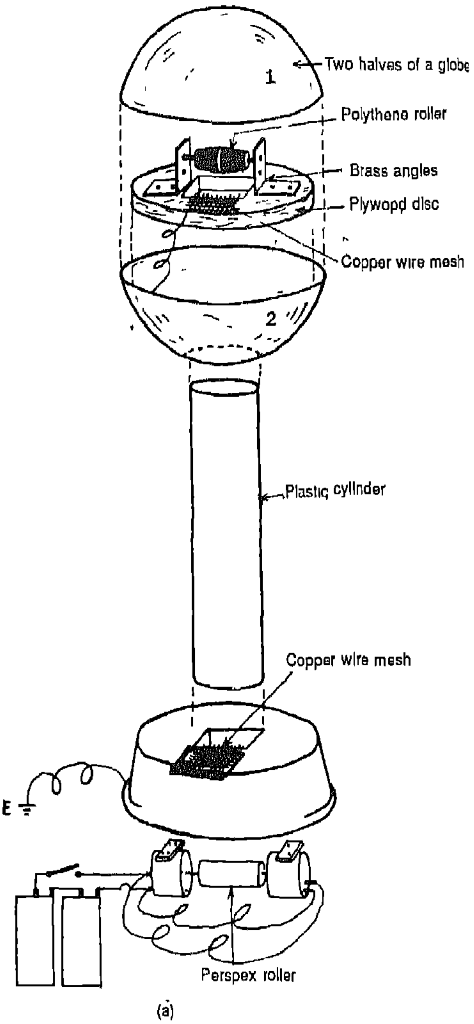


Fig 1.40

figure shows these parts separated out, for the sake of clarity.

Now, open a 20 cm or 25 cm metallic geography globe at the equatorial seam. (If a geography globe is not available, use two semi-spherical pans, placed face to face to form an approximate sphere). Cut a circular hole in the centre of the lower semi-sphere so that it slips over the top of the plastic cylinder tight fit Fix the lower semisphere on the top of the plastic cylinder with the help of 8 aluminium angles of about 12 mm x 12 mm.

Next, place into the lower semi-sphere a circular plywood disc of about 15 cm diameter. In the centre of the disc make a square hole 7.5 cm x 7 5 cm Mount two aluminium angles of about 3 cm x 3 cm on two opposite sides of the hole and bolt them to the plywood. Then place an aluminium rod as a shaft through the upper holes of the angles. Remove the shaft and slip a polythene roller over the shaft to serve as an upper pulley for the rubber belt, which will be later fitted over it.

Then fit the shaft back into the angles.

Fasten 5 cm x 5 cm square piece of copper wire mesh such that there is a few mm gap between it and the polythene roller. When belt will run on the roller, the sharp ends of the copper wire mesh will be 1 mm or 2 mm away from the outer surface of the belt. The mesh is a little above the horizontal plane of the shaft and serves as the upper electrode. By a short length of copper wire, connect this mesh to the metal of the lower half of the sphere. Then fix the upper semisphere in position.

Procure two miniature 3 volt motors of the type sold in hobby shops. Bolt them to the inverted bottom of the pan and inside the pan so that their shafts face each other. They are connected to a dry cells battery in such a way that the motors run in the same direction when their shafts are facing each other, so that the belt is driven in the same direction by both motors. The shafts of the two motors facing each other fit into a 5 cm roller of perspex. First drill a small hole in the centre of each plane face of the roller Then force the shafts of the motors into opposite ends of the perspex roller A cylinder of wood can also be used if it is first thoroughly treated with clear lacquer, which makes the wooden surface a better insulator and gets positively charged on friction with the rubber belt.

Now slip a rubber belt about 1.5 mm thick and 3.5 cm to 4 cm wide over the upper and lower rollers (Fig. 1.40b). Then fix a copper wire mesh in the bottom to serve as the lower electrode. It should be in same horizontal plane as the shafts of the two motors and about 1 mm or 2 mm away from the outer surface of rubber belt.

To test the satisfactory operation of the device, hold a stiff wire attached to a wooden handle. One end of the wire rests on the aluminium base. The other end of the wire has a small metal knob in it. Gradually decrease the distance between the knob and upper sphere. At a certain distance, a spark is seen to jump between the knob and the upper sphere. Under dry dust free conditions at standard temperature and pressure, spark discharges of 1 cm, 7 cm and 12 cm length occur when the p.d.'s are roughly 30kV, 250kV and 750kV respectively. Upto 200,000 volt can be generated by your Van-de-Graaff generator, if you have properly constructed it.

FLUE-ASH PRECIPITATOR

An average coal-fired power station, where this device is not used, throws about 30,000 kg. of flue-ash per hour into atmosphere causing much pollution. Precipitator is installed between the chimney and the main building which contain the coal bunkers, boiler house and turbine hall It removes 99% of the ash from the flue-gases before they reach the power-station chimney, the out let for flue-gases to atmosphere. Electrostatic precipitation is also important in the steel, cement and chemical industries, where flue-gas out-

puts are high A precipitator is made of a number of thin wires and plates The wires are negatively charged to a high potential. Strong electrostatic field near any wire attracts particles of ash, gives them a little negative charge and then repells them. The particles are then attracted to the positive plates From the positive plates, these are collected mechanically and used as a by-product

TOPIC VIII. GRAINY NATURE OF ELECTRICAL CHARGE

***1.36 (Experiment): To study the grainy nature of electric charge and find the magnitude of electronic charge by Millikan's oil drop experiment**

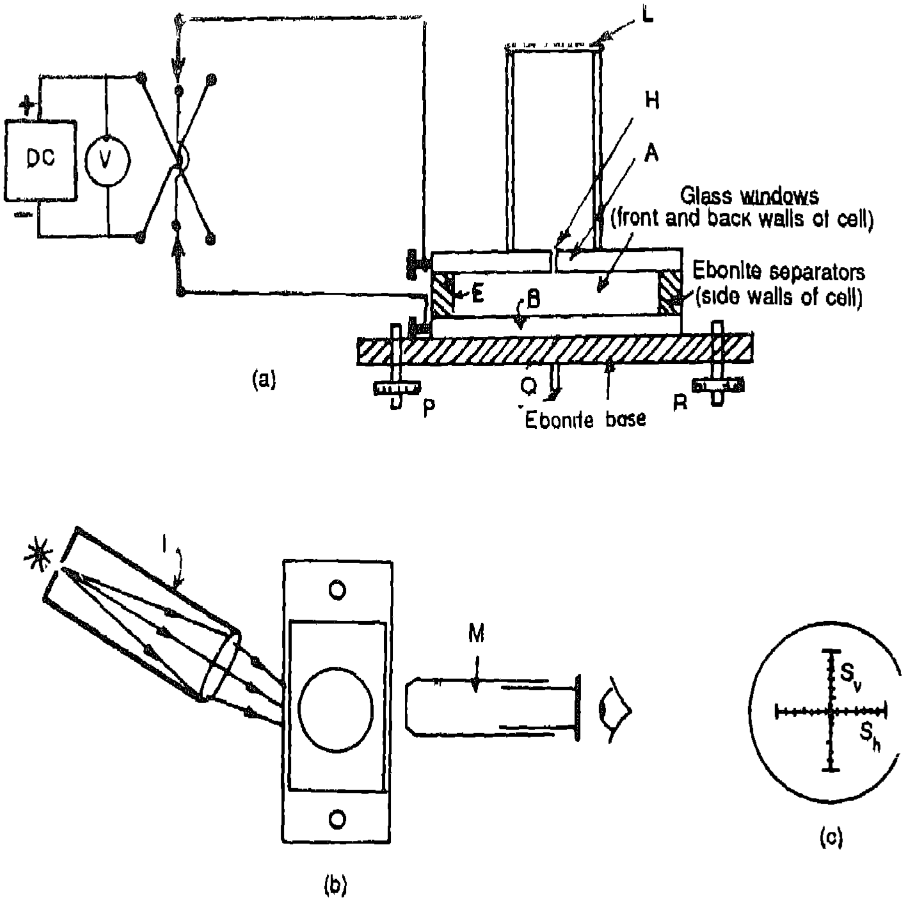


Fig. 1.41 *The Millikan's oil drop experiment (a) Capacitor Unit, (b) plan of optical arrangement, (c) vertical and izontal eye-piece scales of microscope*

N.B. This is a difficult experiment and may be attempted by more skilled students, if the apparatus is available in the school The whole class should study this experiment through a film before any student takes up this practical work

Apparatus Two parallel plates, A and B of brass, each about 5 cm x 5 cm in size and separated from each other (Fig 1 41a) by about 5 mm with the help of ebonite separators, E which make side walls of the chamber so formed between the plates The upper plate has a central hole, H for the passage of oil drops into the chamber A wire is provided for insertion through the hole for (a) cleaning the hole of dust particles and attached oil drops of film and (b) calibration of microscope scale It is called the capacitor unit as the two parallel plates make a capacitor The chamber is closed by glass windows, W in the front and back
2 A power unit giving d c stabilized and filtered voltage (continuously variable from 0 to 500 V) to be applied to the capacitor plates through a 3-way switching arrangement which can also reverse the polarity of plates (and thus the direction of field between them) whenever needed. The 3-way switching arrangement includes a position of the switch in which the plates are disconnected from power unit and are short circuited, before reverse voltage is applied.
3. A high resistance voltmeter (at least 10,000 ohm/volt) for measuring p d applied across the capacitor
4. Oil sprayer (e g scent spray) containing a 'thin' oil of low vapour pressure (clock oil or light lubricating oil)
5. β-radiation source, with handling foreceps
6 An illumination Unit I which provides a converging beam of light which enters between the plates through back window (Fig. 1.41b) A microscope M is arranged normal to front window of the capacitor The eyepiece of the microscope has vertical horizontal scales (Fig. 1 41c) This optical arrangement combines with capacitor (item 1) to make a single equipment, commonly called Millikan's apparatus It can be levelled with the help of three levelling screws

Procedure Make the capacitor unit horizontal by the levelling screws. Insert the wire through central hole in upper plate Adjust the illumination unit so that its beam converges on the wire Adjust the microscope so as to see a clear sharp image of the wire and there is no parallax between this image and the eye-piece scales Note the diameter of the wire on the horizontal eye-piece scale as also by a screw guage This measurement is used to calibrate the eye-piece scale. The whole set up is enclosed in a cylindrical container.

There is a hollow cylinder, C covered by a lid L attached over the upper plate. It prevents any draught of air from entering the capacitor unit through hole in the upper plate Remove the lid of the hole excluding cylinder, gently spray a cloud of fine oil drops into the cylinder and replace the lid After a short while some of the oil drops make their way through the central hole in upper plate of the capacitor, and become visible in the microscope field. Careful adjustment of inclination and focus of the illuminating beam will enable the drops to be seen by scattered light as bright points of light against a subdued background but with sufficient general illumination to permit taking readings against the eye-piece scales (which have black ink markings).

After some practice, droplets can be observed and followed as they fall between the plates Of course, due to optical inversion due to the microscope, they will appear to be rising The droplets usually acquire electric charge by friction with air molecules when being sprayed, before they enter the capacitor unit Apply a p d of about 300V between the plates and look for drops whose speed becomes slower or faster quite a bit Reject the ones which move very fast downwards or upwards and thus have too strong a charge They settle down on lower or upper plate. Thus obtain a charged and brightly illuminated oil drop, which comes to rest by a voltage of between 100V and 500V applied to the plates in appropriate direction By suitable adjustment of the microscope bring this drop in sharp focus along vertical scale of the eye-piece

By increasing the voltage bring the drops slowly to the top of the chamber (i e the bottom of the field of view of microscope) Then reduce the voltage until the drop is stationary Record the reading of the voltmeter Bring the 3-way switch in the position which disconnects the power unit from plates and short circuits them As the drop falls down by force of gravity alone, start the stop watch to find the time for the drop to fall through a certain distance (which must not be less than half the total length of vertical scale) When the free fall is completed, stop the watch and 'catch' the drop by switching on the voltage which brings it to rest Then record the reading of stop watch and distance through which it fell Restore the drop to top of the chamber and repeat. In this manner take about six to eight readings for voltage and velocity of free fall

Now to change the charge on the drop, Bring the β-source near the entrance hole in the upper plate whilst the drop is at rest When the drop moves, remove the β-source and bring the drop to rest by changing the applied voltage. As before, take about 6 to 8 readings for (i) the voltage which makes it stationary and (ii) the velocity of free fall Continue till readings for about 10 or 12 charges on the same drop are taken. Total process will take about 30 minutes to an hour with proper practice You can also change turns for observing the same drop, while the drop is stationary.

Sometimes charge of the drop may change by itself on account of a cosmic ray particle or an ionised molecule in

air being captured by the drop This does not significantly alter its mass, as its mass is of the order of 10^{13} or 10^{14} molecules of oxygen or nitrogen Whenever the charge changes by itself, your previous set of observations is over and new set of observations starts.

It may happen that you lose a drop after too few observations You can start with a new drop, as your calculations take account of mass of the drop The velocity of free fall, v, (i e terminal velocity under force of gravity alone) is given by

$$\frac{4\pi}{3} r^3 (\rho-\rho')g = 6\pi\eta r v \qquad (1)$$

where r = radius of the drop

ρ = density of oil sprayed to make drops

ρ' = density of air

g = acceleration due to gravity

η = viscosity of air

When the drop is made stationary by application of a voltage V, i.e. a field V/d (d is separation between the plates), this voltage is given by

$$\frac{4\pi}{3} r^3 (\rho-\rho')g = q\frac{V}{d} \qquad (2)$$

where q is the charge on the drop All other quantities being known, you can find r by equation (1) and then q by equation (2). The formula to calculate q directly, is obtained by eliminating r.

$$q = \frac{4\pi d}{3V}\sqrt{\frac{\left(\frac{9}{2}\eta v\right)^3}{(\rho-\rho')g}} \qquad (3)$$

The viscosity of air η changes significantly with room temperature. If the room temperatue changes by not more than about 2°C during the experiment, observe it in the beginning and at the end of the experiment. Thus find viscosity of air at the average room temperature during the experiment, using the standard tables

If room temperature changes faster, find the temperature at the beginning of each set of observation Since the density of air, ρ' is about one thousandth of that of oil, it may be neglected in the calculations

Arrange the various values of q thus obtained in ascending order, make a bar graph of the values (Fig 1.37) and see that they make groups of values The values within a group are close together. Find mean of each group Each group mean is an integral multiple of a fundamental charge You can easily guess that integer and thus find the fundamental charge from each group mean.

Observations:

(1) Calibration of microscope.

Diameter of wire =1 _____ m 2. _____ m
(measured by 3 _____ m 4 _____ m
screw guage) 5 _____ m 6. _____ m
Average diameter = _____ m

Number of divisions on eye-piece scale equivalent to wire diameter = _____

∴ One division of eye-piece scale = _____ m

Distance between plates, d = ____ m

(2) Oil density ρ = _____ kg m^{-3}

Density of air ρ' = _______ kg m^{-3}

$\rho - \rho'$ = _____ kg m^{3}

(3) Observations with oil drop

(a) Room temp = _____°C,

Viscosity of air, η = _____ Pa.s.

S.No	*Distance (scale div)*	*Time (s)*	*Speed, v (div. per s)*	*Voltage V (V)*	*Mean speed v (ms^{-1})*	*Mean Voltage V (V)*

Charge on the drop, q =

(Repeat these observations for various drops and various charges on each drop)

S.No. of group	*Values of q* (C)	*groups mean* (C)	*electronic charge* (C)

Mean value of electronic charge = _____ C

THEME II

Current Electricity

IN Theme I, we studied as to how bodies can be charged and how these charges interact amongst themselves An electrostatic charge produces an electric field in the surrounding space and if an electric charge, which is free to move, is placed in this field, it moves from a point at higher potential to a point at lower potential. Conductors allow charges to flow through them easily. Thus if a potential difference is established between two points of a conductor, charge will flow from a point at higher potential to a point at lower potential. Flow of charge constitutes an electric current.

A steady flow of charge through a conductor (i.e. a steady current) will need a steady potential difference across it. This steady, potential difference can be provided by a primary or a secondary cell due to the chemical action taking place inside it In this theme, we will study the laws concerning the flow of charge through solids and liquids under a potential difference. We will also study a variety of phenomena such as thermal, chemical, etc. that are caused because of the flow of charge. In all these phenomena, there is merely an interconversion of energy, i.e. conversion of electrical energy into thermal and vice versa, or conversion of electrical energy into chemical energy and vice versa

TOPIC I CONDUCTION OF CHARGE

2.1 (Demonstration) : To demonstrate that charge flows when there is a potential difference.

Take a large metallic conductor A (about 20 cm long and 8 cm in diameter) supported on

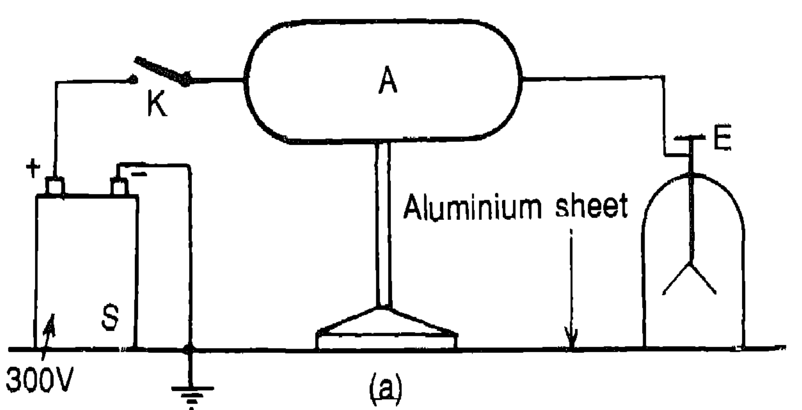


Fig. 2.1 *Electric charge flows from conductor at higher potential to earth Electric current thus generated is indicated by neon lamp.*

an insulated stand (Fig. 2.1a) Charge it with the help of a 300 V DC power supply, S. First earth the conductor A and ensure that it has no charge by connecting the disc of a sensitive electroscope E with it For proper earthing of the bases of the electroscope and conductor put them on a large aluminium foil or sheet Next, connect A to the positive terminal of S, the power supply placed on the same aluminium sheet (-ve terminal internally earthed) Switch on the power supply. Check, if A has got charged, by observing the leaves of the gold leaf electroscope E.

Now remove connection of A from S. Hold a neon lamp by one of its metallic caps P, and touch the other end with the second cap Q to the conductor A, while you keep your other hand on the aluminium sheet (Fig 2.1b). Do you notice a momentary glow in the neon lamp? If so, it shows the flow of electrostatic charge from A to earth through your body. After the glow you will also notice that the leaves of the electroscope have collapsed, indicating that there is no charge left on the conductor A Thus in this case the charge flowed from a conductor at positive potential to the earth

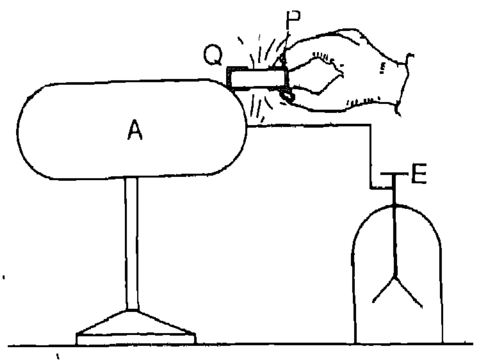


Fig 2.1(b)

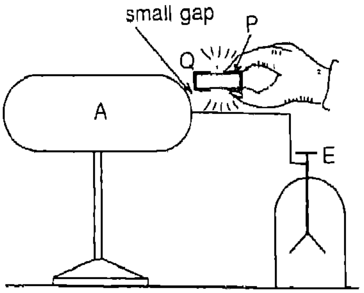


Fig. 2.1(c)

Note . 1. Suppose instead of removing the connection of the power supply S to the conductor A, the conductor A is kept connected to S Then you touch the end Q of the neon lamp to the conductor A, while holding the other end P in hand. You will observe that the neon bulb now glows steadily. The power supply continues to supply positive charge to the conductor A (or pull out electrons) and maintains the potential difference between the aluminium foil and the conductor A. Thus you conclude that to obtain a steady flow of charge you require a steady potential difference

2 It is possible on a dry day to see the glow in the neon bulb, if the cap of the bulb is brought close to (not touching) the conductor A (Fig. 2.1c). If the room is relatively dark you can also see a spark jumping from the conductor A to the cap of the lamp

2.2 (Activity): To study the characteristics of the flow of charge under a potential difference.

(a) Take two large spherical metallic conductors A, B on separate insulated stands. Earth them separately and ensure with the help of a sensitive electroscope that both have no charge coon them. Bring A and B close so that they are in contact. Next take an electrophorus and charge it. Take the charged electrophorus disc D near one of the conductors. The two conductors would get charged by induction (Fig 2.2a). Hold D, and separate A and B in its presence. After A and B are separated, remove the electro-

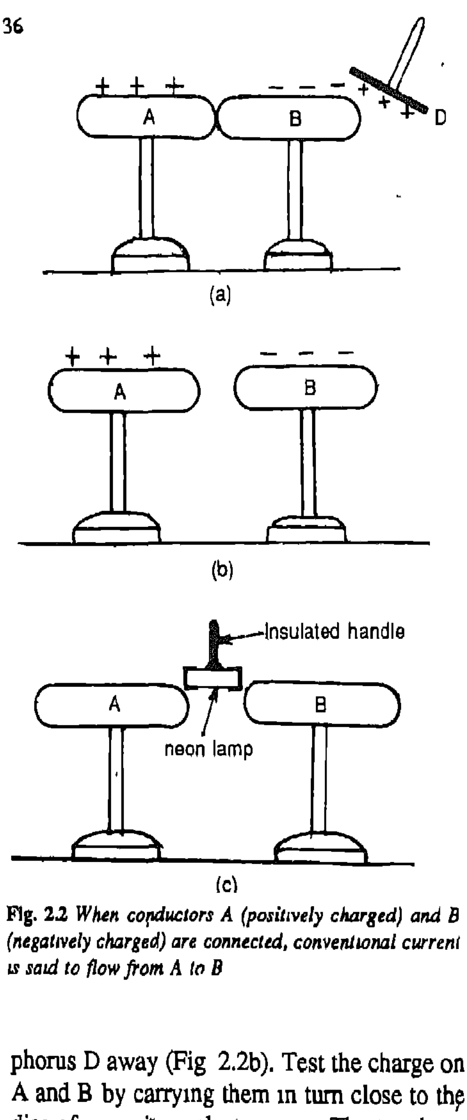


Fig. 2.2 *When conductors A (positively charged) and B (negatively charged) are connected, conventional current is said to flow from A to B*

phorus D away (Fig 2.2b). Test the charge on A and B by carrying them in turn close to the disc of a sensitive electroscope. The two have equal but opposite charge. Thus one has positive potential and the other has a negative potential with respect to the earth, i.e. they have a potential difference between them.

Take a neon lamp. Fix an insulating handle in the middle of the neon lamp with the help of a transparent adhesive tape. Touch one end of the neon lamp with the conductor A which is charged positively and the other end with the conductor B charged negatively (Fig. 2.2c). If the room is moderately dark, you will see a momentary glow in the neon lamp, which shows that a momentary current passed through the neon lamp. Take away the neon lamp and test whether there are any charges on A and B, by electroscope. You see that there is no net charge on A as well as on B This shows that either (i) positive charge flowed from A (at higher potential) to B (at lower potential) and neutralised the charge on B, or (ii) negative charge flowed from B (at lower potential) to A (at higher potential) and neutralised the charge on A.

Experimentally there is absolutely no difference between statements (i) and (ii) above We know from advanced study of solid state physics that statement (ii) is correct However, we may talk in terms of flow of positive charge in discussing the behaviour of electrical circuits for the sake of convenience. This imaginary flow of positive charge is often referred to as the "conventional current".

(b) Take two electrolytic capacitors A and B each of 32μ F (500 volt rating), which are commonly used in electronic circuits. The plate of an electrolytic capacitor marked (+) must be given positive charge and the other negative charge. Note that if you charge them the opposite way, the capacitor gets damaged. Therefore, earth the negative plate of A and the positive plate of B (Fig. 2.3). Connect identical sensitive electroscopes to the second plate of A and the second plate of B, which are not earth connected.

Now take a 300 volt DC power supply. Place it on a wooden board so that its casing is not earth connected. For a while touch its positive terminal to second plate of A and negative terminal to earth. Thus second plate of A is raised to 300 volt positive potential and its electroscope shows a divergence. Similarly raise the second plate of B to 300 volt negative potential by the same power supply and then discon-

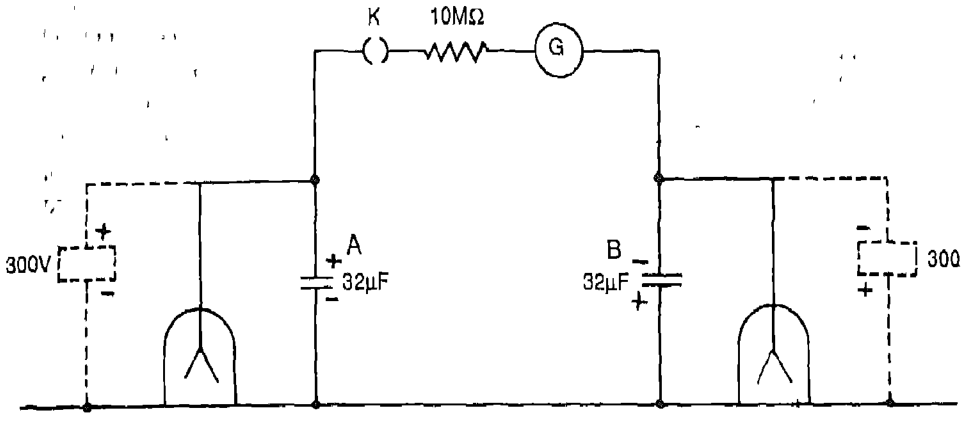


Fig. 2.3 *Such a large quantity of charge can be stored in electrolytic capacitors that flow of charge can be observed for a quite long time interval*

nect the power supply. The amount of electrostatic charge on each capacitor is about ten million times of that an conductors A and B in experiment (a) above.

A galvanometer (Full scale deflection current $\approx 50\ \mu A$) is already connected between second plate of A and second plate of B, through a 10 MΩ carbon resistor and key K. Now close the key K so as to connect the two plates. You will see that the galvanometer shows a deflection The direction of deflection will indicate that the conventional current flows from A (which is at positive potential) to B (which is at negative potential). The amount of charge on the capacitors being so large, is not depleted in an instant as happend in experiment (a) above, and you can observe the current flow comfortably for a few minutes. As the charge on the two capacitors gradually diminishes, you can watch the leaves of electroscopes gradually col-

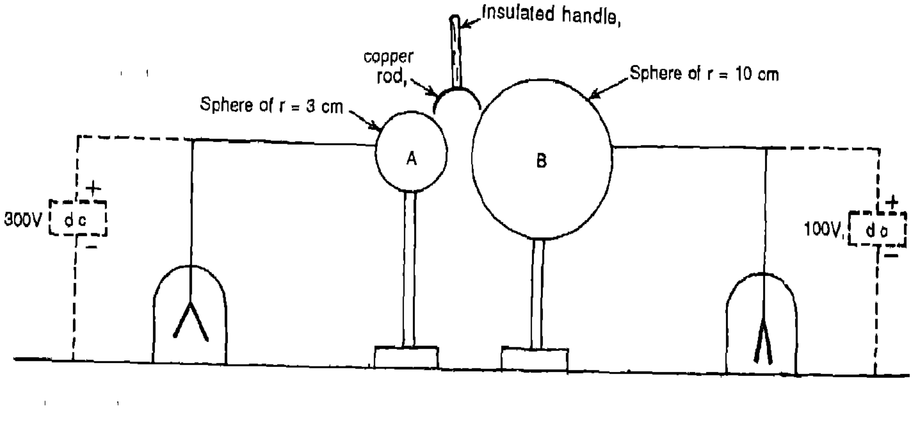


Fig. 2.4 *A gives charge to B though it already has less charge*

lapse.

(c) Take two insulated spherical conductors A and B with a radius of 3cm and 10cm respectively. Also take two identical electroscopes. Connect one to each conductor. (Fig. 2.4)

Connect A to positive terminal of a 300 volt DC power supply earthing the negative terminals. By so doing you are charging A to a potential of +300 volt. The leaves of the electroscope connected to A show divergence. Remove the connection of the power supply.

Similarly, connect B to positive terminal of a 100 volt DC power supply with the negative terminal earthed. By so doing you are charging the conductor B to a potential of +100 volt.

Disconnect the power supply.

We now have A with a radius of 3cm charged to a potential of 300 volt and B of radius 10cm charged to a potential of 100 volt. You have seen in the previous theme that charge on a conductor $Q = VC$, where, V is potential to which it is raised and C is its capacitance. Capacitance of a spherical conductor is proportional to its radius. Thus the capacitance of A = $3k$ (k is the constant of proportionality) and that of B=$10k$. Thus the charge on A is 300 x $3k$ = 900 k units, whereas the charge on B is 100 x $10k$ = $1000k$ units.

Thus the charge on B is greater than the charge on A, but the potential of A is greater than the potential of B. Now connect the conductors A and B with a copper rod fixed to an insulating handle (Fig. 2.4.) Watch the two electroscopes when A and B are touched by the copper rod.

Interestingly you will find that the electroscope connected to A shows a slight decrease in divergence of leaves and the electroscope connected to B shows a slight increase in divergence. This divergence of leaves of electroscope connected to B indicates that B has acquired a charge from A and its potential has increased. Similarly the collapse of the leaves of the electroscope connected to A indicates that A has lost charge and its potential has fallen down. Though A had less charge, still it gives away some of its charge.

This experiment clearly shows that irrespective of what amounts of charge are on the conductors, positive charge flows from a body at higher potential to a body at lower potential.

Play with these conductors raised to various potentials and observe what happens to the leaves of the electroscopes connected to the two conductors on connecting them with a copper rod held by an insulated handle. You will find that irrespective of the charges on the conductors, positive charges will always flow from a conductor at higher potential to the one at lower potential.

This flow of charge from one conductor to the other is similar to the flow of water from one container to the other container connected to it. Whatever the quantity of water in these containers, water will always flow from the container which has higher level of water to the one which has lower level of water.

TOPIC II VOLTAGE-CURRENT RELATIONSHIP

2.3 (Experiment): Study of relation between potential difference across a metallic conductor and the current flowing through it (Ohm's Law).

Formula: If a current I flows through a conductor, then the potential difference V across the two ends of the conductor is proportional to I, i.e., $V \propto I$

or, $V = IR$

This relation holds good provided the physical conditions (temperature and pressure) of the conductor do not change.

Apparatus: A 28 SWG constantan wire about 3 metre long, milliammeter (0-500 mA), voltmeter (at least 1000 ohm/volt, range 0-5V), rheostat, source of DC (four dry cells or a 6V

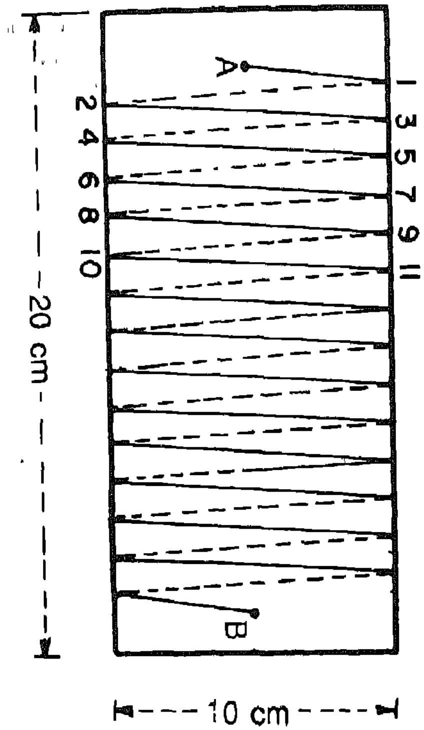


Fig. 2.5 *A long resistance wire can be easily managed by winding it over to a strip of card-board*

accumulator), one way key.

Procedure Take about 3 m length of the wire. In order to make it manageable (so that two distant points on it don't get short circuited), wind it over a strip of card-board about 10 cm wide and 20 cm long (Fig. 2.5) Fix the two ends in terminals A and B, to which connecting wires of copper can also be connected by an extra nut.

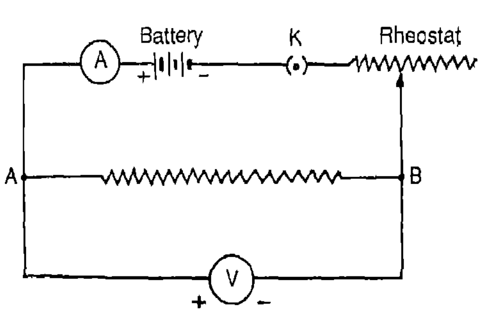


Fig. 2.6 *A long resistance wire can be easily managed by winding it over a strip of card-board*

Make connections as shown in Fig 2.6., so that the voltmeter measures the potential difference between the ends AB of the wire Ammeter measures the current passing through the wire (plus that through the voltmeter, but the current through the voltmeter is very small and is negligible). The rheostat enables you to increase or decrease the current by decreasing or increasing its resistance as and when you desire

Check that the pointers of the ammeter and voltmeter are at their zero mark when the key (K) is 'off'. If not, adjust the pointer of each with the help of a screw provided in them for this purpose. Alternatively, you may note the positions of their pointers with no current flowing and later correct each observed reading for this zero error.

Change the resistance of rheostat in steps from the highest to the lowest value, so that value of current or the voltage does not exceed the respective ranges of the ammeter or the voltmeter. Take care that the wire AB also does not get heated. This can be ensured by passing momentary current. For each setting of the rheostat, note the value of current I flowing in the wire and the potential difference V developed across it. Take at least 5 sets of observations. Plot a graph between I and V, taking potential difference along the Y-axis. Do you find the graph to be a straight line passing through the origin ?

Find the slope of the graph:

$$\text{Slope} = \frac{\text{Potential difference across the wire}}{\text{Current passing through the wire}}$$

This slope is the resistance of the wire.

Repeat this experiment for at least two different lengths and two different diameters of the wire of the same material. Do you find any change in the slope of the graph when you change the length and/or the diameter? Do you find that the resistance increases with an increase in the length and decreases with an increase in the diameter of the wire ?

Question: When there is no current passing in the wire B, you adjust pointers of ammeter and voltmeter at zero marks. Thus, the reading "P.D. = O volt for current = O ampere" is by your intention and not what you observe by experiment. The point representing this observation on the graph is the origin. While honestly drawing a straight line graph closest to the marked points, will you neglect the origin or treat it also as one of the observations?

Notes· 1. Current should be passed for a short time only while taking a set of readings.

2. Dry cells should be used intermitently.

2.4 (Demonstration): Analogue of 'electron drift' in a metallic conductor on application of potential difference.

You know that electric current flowing in a metallic wire results from the drift of free electrons (Text book Chapter 3) consequent on application of potential difference along the potential gradient. A mechanical analogue can help us to visualise these phenomena. We shall use the model that may be made as per the guideline provided in the Appendix 2.

Take the mechanical model (Fig. 2.7). The tiny beads in this model represent the free electrons in a metal, whereas, the fixed steel balls represent the relatively fixed atoms/ions in the crystalline lattice of a metallic conductor say copper. The beads can be fed along the edge A and can be collected along the edge B. There is also an arrangement to raise A with respect

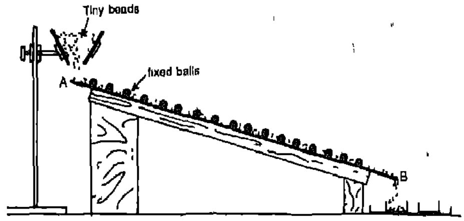


Fig. 2.7

to the edge B.

Make the plane on which steel balls are fixed horizontal. In this case the edge A is at the same

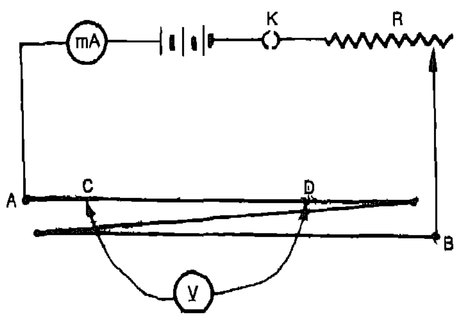


Fig. 2.8

level as B. By analogy we say that A has the same potential as that of B, or there is no potential difference between A and B. See the beads in motion by a mechanism which vibrates the whole channel in a horizontal direction perpendicular to its length. Then beads strike the steel balls and get deflected. For a given bead, the direction in which it moves constantly changes. There is no drift velocity, or the velocity of the beads is truely random. There is no such transfer of beads from the source A to the sink B

Raise the edge A with respect to the edge B. Now observe the movement of the beads. The motion is still random but there is a marked tendency for the beads to drift towards the edge

B. After some time, the beads will start collecting at B Measure the rate of collection. Transfer the beads collected at B to the edge A so as to ensure steady flow of beads. Now change the difference in the height of A relative to B and once again measure the rate of collection. Do you notice a relation between the rate of collection and the difference in the height of A and B?

In much the same way electrons in metals, move in a crystalline lattice, colliding with atoms/ions. Only under potential difference, they acquire a drift velocity causing a net flow of electrons, constituting an electric current

2.5 (Demonstration): To demonstrate the fall of potential along the length of a conductor when a steady current flows through the conductor.

Take a SWG 28 constantan wire 3 metre long. Connect the circuit as shown in figure 2.8 the voltmeter V has two sliding contacts C and D. These can be two crocodile clips Thus any distance between C and D can be made. Pass a definite current through the conductor AB. Make contacts C and D. Observe the potential difference as measured by the voltmeter. Note down the potential difference. Now make contacts C and D to the metal wire AB at any other two points, keeping the distance between C and D fixed. In each case find out the potential difference. You will observe that if the distance between C and D is fixed and wire is of uniform cross section, the potential difference between C and D for a given current through AB will always be same, within experimental error.

Repeat the same experiment, but this time, change the distance between C and D in each reading. Measure the potential difference and the length between C and D You will observe that as the length between C and D increases, the potential difference across C and D correspondingly increases in the same proportion provided the cross section of the wire is the same.

This drop in potential difference can be compared with the drop in pressure difference when water flows through a tube with an apparatus as shown in the Fig. 2.9. The water level in vertical tubes goes on falling almost linearly with

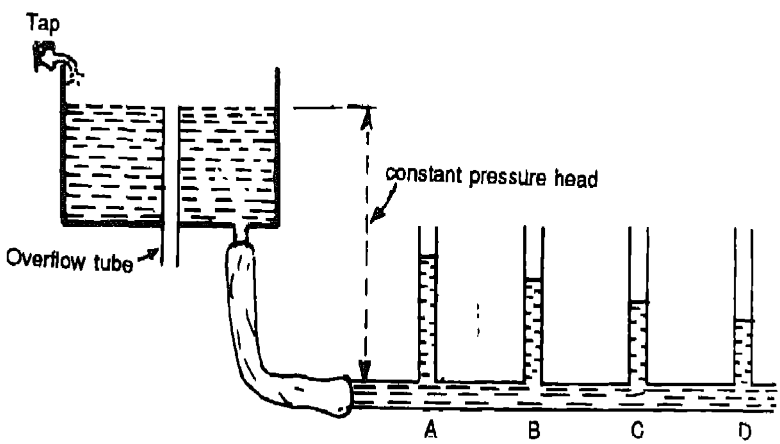


Fig. 2.9 *Pressure falls linearly along a tube of a uniform cross-section when water flows in it Similarly, potential falls linearly along a wire of uniform cross-section when an electric current flows in it*

length from A

When the tube does not have uniform cross section, such as shown in the figure 2.10, the potential drop across A and B is much smaller

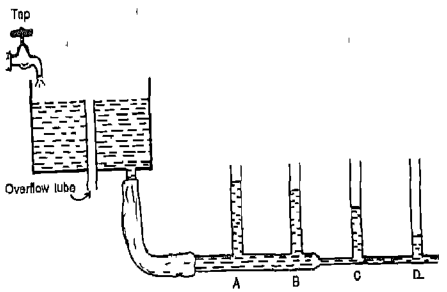


Fig. 2.10

than the potential drop across C and D, even if length AB and CD are equal This merely shows, that the resistane to the flow of water across AB is smaller than the resistance to the flow of water across CD. This experiment shows that the resistance to the flow of water under pressure difference depends not only on the length of the tube but also on its cross-section.

2.6 (Activity): To study the dependence of resistance on length and cross section of the conductor.

Take three wires (1) SWG 28, 3 metres long, (2) SWG 28, 2 metre long and (3) SWG 24, 3 metre long. Fix these wires on three boards. Take one of the boards say having SWG 28, 3 metre long wire fixed on it. Connect the circuit as in experiment 2.3 and shown in the Figure 2.6. As described earlier, determine resistance of the conductor AB. Replace the board on which SWG 28, 3 metre wire is fixed by the board on to which SWG 28, 2 metre wire is fixed. Measure its resistance. Now replace this board by the board on to which SWG 24 and 3 m long wire is fixed. Measure once again the resistance of this wire.

You will find from your measurements that the resistance increases as the length increases. Similarly, resistance is seen to increase as the cross-section of the wire decreases·

$$R \propto l$$

$$\text{and } R \propto 1/A,$$

where l and A are length and cross-section of the wire.

Thus $R = \rho \frac{l}{A}$ where ρ is the constant of proportionality characteristic of the material of the three wires and is called the *resistivity* of that material.

***DETERMINING THE RESISTIVITY OF SILICON WITH FOUR PROBE TECHNIQUE**

Four probe technique is a standard technique in semiconductor technology to measure the resistivity of a semiconducting material As the name indicates, it has four contacts A,B,C and D These contacts are essentially pressure loaded contacts The simplest form of the four probe apparatus is shown in Figure 2.11. Current is passed through the probes A and B The potential difference is measured across C and D. Knowing the potential differences across C and D and the current flowing through AB, one can determine the resistance between C and D Knowing the thickness of silicon wafer and the distance between C and D, resistivity of silicon can be determined

2.7 (Experiment): To measure the resistance of a metal wire by Wheatstone Bridge (Metre Bridge).

Procedure and Theory: We have seen in our class

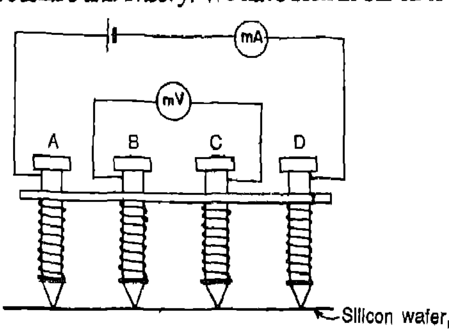


Fig. 2.11 *Four probe technique for determining the resistivity of a silicon wafer.*

room text that if resistances P, Q, R, and S are connected in the form of network as shown in the figure 2.12 and if there is no deflection in the galvanometer G (or the point B and D are the same potential) then

$$\frac{P}{Q} = \frac{R}{S}$$

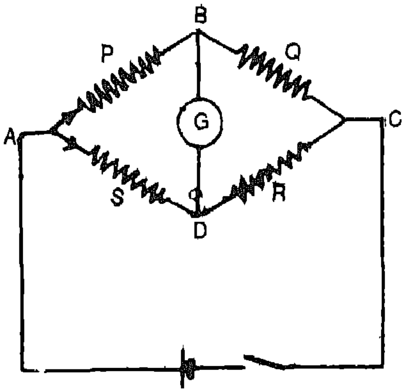


Fig. 2.12 *The Wheatstone bridge*

We use this relationship to determine an unknown resistance R if P, Q and S are known.

Metre bridge which utilises this principle is shown in fig. 2.13a. AC is a metre long constantan wire stretched along a metre scale M. This wire is fixed at A and C. The unknown resistance is connected between A and D. Resistance box from which a known resistance is included in the circuit as desired, is connected between D and C. A sensitive galvanometer G is connected between D and the moving contact B A cell with a suitable rheostat is connected between A and C. This arrangement forms the Wheatstone bridge, as shown in the Figure 2.13b.

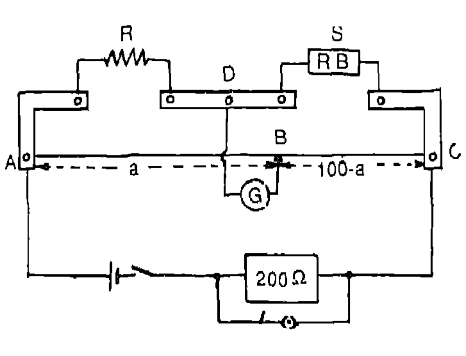


Fig. 2.13 (a)

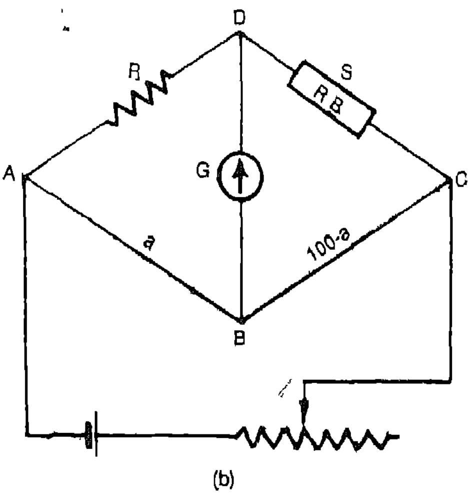


Fig. 2.13 (b)

Take out a suitable resistance S from the resistance box RB. Move the moving contact to obtain a position B in such a way that on making contact at B there is no deflection in the galvanometer. If you make a contact at a point between A and B then there is deflection on one side, whereas if you make a contact between B and C, there is a deflection in the other side. B is called the *null point*. Measure AB and call it a; BC is then $(100-a)$. If the resistances per unit length of the constantan wire is ρ, then we have $R/S = \rho a/(100-a)\rho$, or $R/S = a/(100-a)$. Knowing S, we can get R.

2.8 (Experiment): To find the specific resistance of the material of metallic wire with the help of Wheatstone bridge (metre bridge).

Apparatus Metre bridge, sensitive galvanometer, resistance box, source of DC, one way key, and about 1 metre long constantan wire -: 30 SWG.

Theory: The resistance R of a wire of certain substance of specific resistance ρ, is given by the formula:

$$R = \rho \frac{l}{A} \text{ or } \rho = R \frac{A}{l},$$

where l is the length of the wire and A is the area of cross-section.

Procedure: Find average diameter of the wire with a screw gauge. Calculate its area of cross-section and record it.

Fix the wire in the terminals of the metre bridge for the unknown resistance. Make the connection as in Fig. 2.13a Follow the procedure of activity 2.6 and take at least three sets of observations by determining the null point B for different values of resistance S.

2.9. (Experiment) : To study the laws of combining the resistances in series and parallel using a Wheatstone bridge (Metre bridge)

Apparatus. Meter bridge, a sensitive galvanometer, two coiled pieces of constantan wire (of different resistances), one known resistance coil, one way key and a source of DC

Formulae

The resistance R_p of the combination of two wires of resistances R_1 and R_2, when connected in parallel, is given by $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$

When the two wires are connected in series, the resistance of the combination, R_s, is given by $R_s = R_1 + R_2$.

Procedure: Using the same circuit and procedure as in experiment 2.6, measure the unknown resistances R_1 and R_2 of two coils of constantan wire inserting them one by one in the gap AD of the meter bridge.

Next connect both the resistances in parallel in the same gap of meter bridge (Fig. 2.14). Ensure that the effective length of each wire is same as it was while taking observtions of these resistances separately. It means that the length at the ends of each which is inserted into the

Observations:

Diameter of the wire , d = _____ m, _____ m, _____ m, _____ m, Mean = _____ m.
Area of cross-section, A = _____ m²

S.No.	*Value of known resistance*, S (ohm)	*Position a, of the null point*, B (cm)	*Length 100-a* (cm)	Resistance of wire $R = S\frac{100\,a}{100-a}$ (ohm)
1				
2.				
3.				

Mean value of R = __________ ohm. Effective length of the wire, l = __________cm.
Specific resistance $\rho = R\frac{A}{l}$ = ________ ohm.

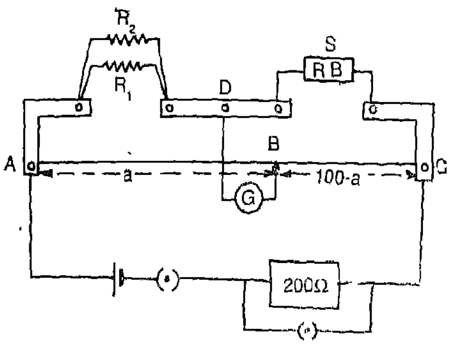


Fig. 2.14

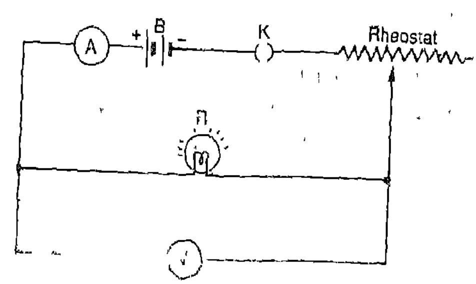


Fig. 2.15 Circuit for the study of voltage-current relationship for a torch lamp

terminals, should be kept the same.

Take three sets of observations for this combination of resistances (in parallel) and calculate the resistance of the combination R_p.

Next, connect the two resistance wires in series (end to end) in the same gap of meter bridge In this case also ensure that the effective length of each wire remains unchanged. It means that the point where the two wires are joined end to end the lengths of the ends that were inserted into the terminals should be twisted together, or inserted into a connector (the device to connect the two wires end to end). Take three sets of observations for this setting and calculate the mean resistance of the combination of the two coils connected in series.

Now compare the measured values of R_p and R_s with their values calculated by using the formulae given above and the separately measured values of R_1 and R_2. If there is a difference in the two values of R_p or of R_s, try to account for this difference.

2.10 (Activity) Study the voltage-current relationship for a torch lamp.

Use the same circuit as in the experiment 2.4 to (study ohm's law for a metallic resistance wire), by replacing the wire with a torch lamp (Fig. 2.15.) In case of this experiment you have not to worry to see that the lamp does not become warm. You should let the current and voltage rise upto the value indicated on the metallic part of the body of the lamp. Take at least eight sets of observations. Starting from maximum, decrease the value of resistance of the rheostat in steps so that potential difference developed across the lamp increases in roughly equal steps. Thus record 8 to 10 observations of current, I, passing through the lamp and voltage V, developed across the lamp.

Plot a graph between I & V, taking V along X-axis. Do you find that different points plotted don't yield a straight line? Draw a smooth curve passing through the different points and the origin (which represents zero current for zero voltage). Calculate the value of resistance, R of the lamp given by $R = \frac{V}{I}$ for each set of observation. Do you find that R keeps changing with I?

Notes: 1. As the resistance of a torch lamp increases with current passing in it, instead of the relation $I = \frac{V}{R}$ try the relation $I = KV^n$, where K and n are constants for the particular torch lamp. Taking logs of the above relation we get $\log I = n \log V + \log K$. Tabulate the

values of log I against corresponding values of log V and plot a graph for these values of log I and log V (Fig. 2.16). If this graph gives a

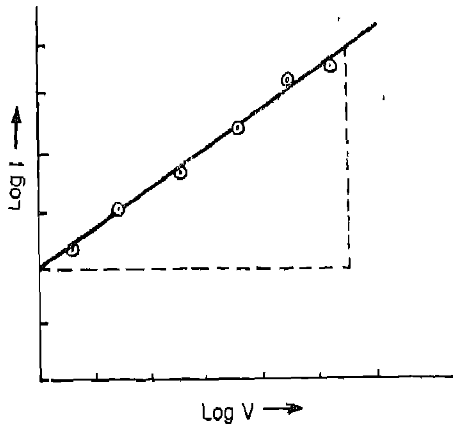


Fig. 2.16 *Graph between log I and log V for a torch bulb*

straight line, its slope (Change in log I/corresponding change in log V) gives the value of n. The intercept on log I axis is the value of log K. Thus you can find the values of K and n for the lamp used.

2. The maximum value of I and V that a torch lamp (manufactured by standard firms) can withstand are indicated on the metallic part of its body. These marks may get wiped off. So it is necessary to note these values from the manufacturer's packing for the lamp.

3. For each pair of readings for I and V, you should pass a steady current and wait for a steady state to be reached. You will notice that for a given applied voltage, first a large current lanes and then decreases to a steady value. The smaller is the current at which a lamp operates, the smaller is the time-lag for it to reach the steady state

2.11 (Experiment) Study of the variation in resistance of a conducting wire with temperature.

Apparatus: Metre-bridge, sensitive galvanometer, standard resistance box, source of DC, one

***COLOUR TEMPERATURE**

In the activity 2.9. above, you may like to record the colour of the torch lamp for each current that you pass through it. You will notice that as current gradually increases, the colour first becomes dull red, then red, then bright red, then orange, then yellowish and so on. This change in colour is essentially due to rise in temperature of the filament. The colour of the glow is characterised by the wavelength, λ_{max} at which the intensity of radiation it emits is maximum (in a spectrum of the emitted radiation). This wavelength (measured is nonometre) is given by the relation

$$T\,\lambda_{max} = 2.8978 \times 10^{6}\ \text{K nm}$$

where T is the absolute temperature of the filament. This relation is called *Wien's law*. The constant on the right hand side is called *Wien's constant*. This relation assumes that the surface of concerned hot body (filament) acts like a perfectly black surface. Thus as T increases., λ_{max} decreases or the colour of the glow shifts from red to yellow.

This relation can be used to determine the temperature of bodies like the Bunsen burner flame, candle flame, filament of electric filament lamp, as also of stars. We record a spectrum of the radiation emitted by the concerned body, find λ_{max} and then calculate the temperature, using the Wien's law. Result so obtained is called *colour temperature* of the body

way key and the given conducting wire coiled on a small wooden strip.

Procedure: Take thin DCC copper wire of 40SWG, about 3m long. Fold it over twice and wind it on a wooden strip about 1 cm wide, 5 mm thick and 5 cm long. Solder stout enamelled copper leads to the ends of the coil. The leads pass through two different holes in the wooden strip to avoid short-circuiting them (Fig. 2.17)

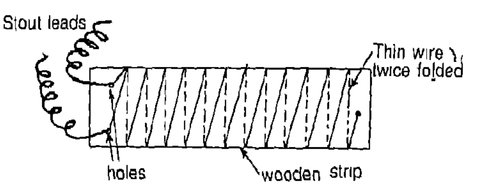


Fig. 2.17 *Copper wire wound on a tiny wooden strip for heating it in a boiling tube*

Use the circuit of meter-bridge as was used for Activity 2.6. Put this strip with thin copper wire in a large boiling tube containing liquid paraffin (or any liquid which does not affect the copper wire and is a good insulator at least upto 100°C). The wooden strip should immerse in the liquid. Put a thermometer alongside the wooden strip in the boiling tube (Fig. 2.18).

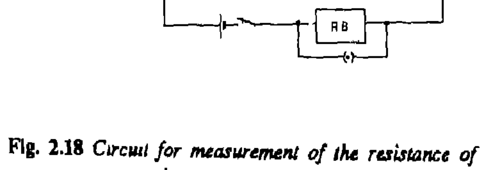


Fig. 2.18 *Circuit for measurement of the resistance of copper wire at various temperatures*

Thus find the null point B_1 for the wire at room temperature; and note this temperature t_1.

Next, put the strip with thin copper wire alongwith the boiling tube in a beaker containing boiling water In a few minutes the liquid paraffin and the wire attain the temperature of hot boiling water. Again find the null point B_2, to right side of the first, indicating an increase in the resistance of the wire. Also note the temperature of the wire in the thermometer, t_2.

Similarly, repeat by putting the boiling tube in a mixture of ice and water, find the null point B_0 to the left of that for room temperature and note the temperature of the wire t_0.

Calculate resistances R_0, R_1, R_2 at the temperatures t_0, t_1 and t_2 respectively. Plot a graph between R and t, taking the former along

If the three points for the three temperatures lie on a straight line, within experimental error, find the temperature co-efficient of resistance:

$$\alpha = \frac{\Delta R}{\Delta t \times \text{resistance of coil at } 0^\circ\text{C}}$$

You can in fact use a coil of metal wire as a thermometer if you know α and the resistance at 0°C. Such thermometers are called *resistance thermometers*. In most cases platinum is used as a material for the wire and the thermometer using platinum wire is called the *platinum resistance thermometer*.

2.12 (Experiment): To determine the melting point of wax using a resistance thermometer.

Apparatus: Same as in previous experiment.

Procedure: Take the coil that you used in the previous experiment. You know its resistance at 0°C (R_0 ohms) and the temperature coefficient of resistance, α. Take a beaker containing paraffin wax. Place this beaker on a

Bunsen flame Let the wax melt. After the wax has fully melted, put in the coil whose temperature coefficient of resistance has been determined. Remove the Bunsen burner. The wax starts cooling. Start a stop clock to measure time for which the wax cools After short time intervals (which may or may not be equal), find the position of null point on the metre bridge. When a null point is obtained, immediately note the time in the watch. Tabulate the data of position of null point against corresponding values of time and calculate the resistance of copper coil at each time

Plot a graph between resistance of copper coil and time. When the wax starts solidifying, its temperature remains stationary till all the wax has solidified So also the resistance of the copper coil remains stationary. Find this stationary resistance R_m of coil from the graph. Then calculate temperature, t_m corresponding to this stationary resistance of the coil using the formula.

$$t_m = \frac{R_m - R_0}{\alpha}$$

This temperature will be the melting point of wax.

SUPERCONDUCTIVITY

Resistance of a metal gradually decreases as its temperature decreases On the other hand, resistance of a semiconductor increases as its temperature decreases There are some alloys and compounds whose resistance decreases with temperature. But, at a certain temperature specific to a material, their resistance suddenly becomes zero (see table 6 in data section). These materials, when their resistance becomes zero, are called *superconductors*. The phenomenon of such materials loosing all resistance to the flow of electric current, is called *superconductivity* The phenomenon was first discovered by Kammerling Onnes in 1912, while studying the resistivity of mercury at low temperatures.

Recently, this field of study has assumed importance

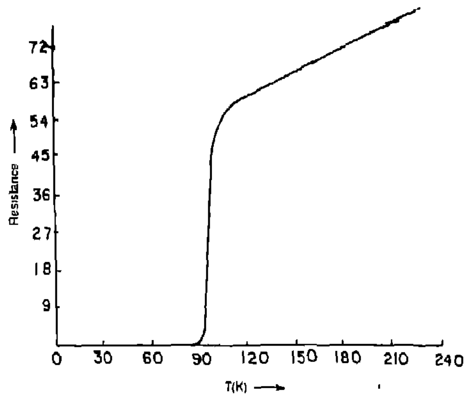


Fig. 2.19 *Varation of resistance of $YBa_2Cu_3O_7$ as a function of temperature*

because of the discovery of some materials which lose their resistivity at fairly high temperatures, say 90 K Figure 2 19 shows the variation of resistance of a compound $YBa_2Cu_3O_7$ as a function of temperature. You will see that this material lose all its resistance below 90 K.

2.13 (Demonstration): To show that resistance of a semiconductor (thermister) decreases with rise in temperature and vice versa.

Take a boiling tube and fill it three-fourth with oil (say SAE 20 mobile oil). Keep it in a water bath kept on a tripod with a gas burner under it. Also suspend a thermometer (0°-110°C) in the oil. Next, take the given thermistor and connect it in the circuit of experiment 2.11 in such a way that it is possible to dip it in the oil bath, while in the circuit. This, would enable you to find resistance of the thermister at different temperatures.

To start with, find the null point B_1 for the thermister at room temperature (t_1) and record the position of the null point and the temperature. Next put the flame on and after a few minutes observe that the null point shifts to left of B_1 indicating that resistance of thermister decreases with increase in temperature.

Remove the flame and surround the oil bath with iced water in a beaker. As the temperature falls below t_1, the null point shifts to right of B_1 indicating that resistance of the thermister increases with falling temperature.

Note 1. This demonstration can also be done using a common carbon resistance used in electronic circuits, but the decrease in resistance with increase of temperature is quite small in that case

2. This experiment may be done as laboratory exercise to study the variation of resistance of thermister with temperature. Take at least two observations of resistance for each of the three temperatures, i e room temperature, ice point, and boiling point of water. For each temperature find the absolute temperature of the thermister (T = 273 + t)

Then tabulate values of log R against corresponding values of $1/T$ and plot a straight line graph between the two (Fig. 2.20)

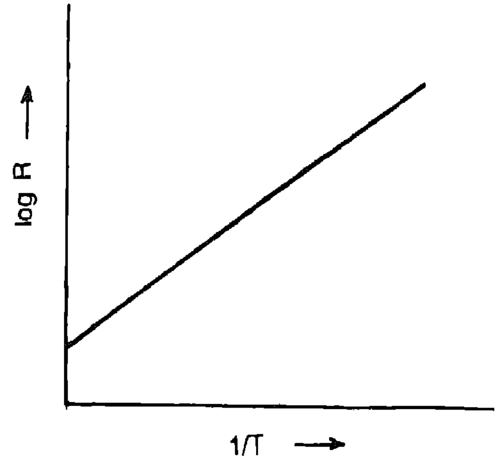


Fig. 2.20 *Relation between resistance and temperature of a thermister*

3. Knowing the variation of resistance of a thermister with temperature, you can use it to measure the unknown temperature of a body.

2.14 (Activity): To study the current voltage relationship for a pn-junction.

Take a semi-conductor diode, say RCA no IN3754 or its equivalent Attach two insulated wires to its two ends with the help of crocodile clips and connect it to a circuit as shown in Fig. 2.21. Close the tapping key K and see if the

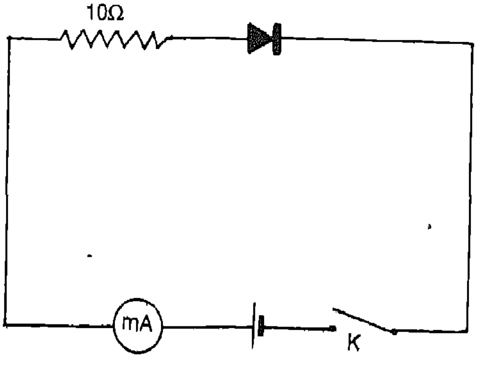


Fig. 2.21

milli-ammeter shows flow of current in the circuit. Reverse the connections of the diode and again see the flow of current in the circuit You would find that the current flows only in one direction (called forward direction), unlike the case of an ordinary resistor.[1]

Fix the diode in the direction allowing the flow of current and make the circuit as shown in Fig. 2.22. Here a 30Ω rheostat is used as a potential divider. Begin with the lowest potential difference and increase it in steps through the permissible range of current and voltage for the diode used (as per its specifications). Take at least five sets of observations of current, I,

[1] In fact a very small current does flow through the diode in the reverse direction It can be checked with the help of an ammeter of a smaller range Thus the diode only has a much higher resistance in reverse direction.

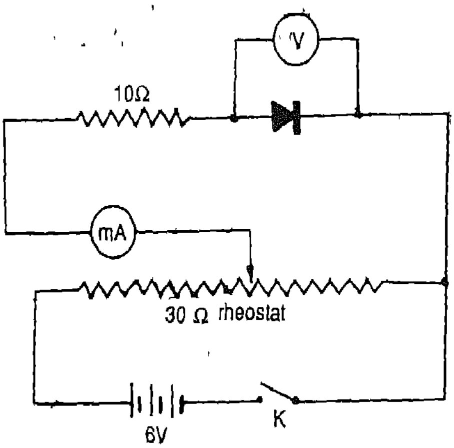


Fig. 2.22 *Circuit for studying the current-voltage relationship for a pn-junction.*

flowing through this diode and the corresponding values of the potential difference, V, across it. Find the resistance of the diode $R = \frac{V}{I}$ for each value of V. Do you find that the value of R is changing? Also plot a graph between voltage and current. Do you get a curve and not a linear graph, unlike the case of a metallic resistor? Does this show deviation from Ohm's law for the pn-junction?

Notes: 1. A high forward current could damage a diode. The 10 ohm resistance in series with the diode in this experiment (Fig. 2.21 and 2.22) is necessary to keep this current within safe limit, just in case the full battery voltage is accidentally applied across it.

2. In the forward direction too, the current may be very small for small voltages applied on it, which may give an impression that it is not the forward direction. It will be quite an instructive exercise to take at least five sets of observations for I and V for both directions of current. Forward direction is characterised by a rapid rise in current when voltage exceeds a certain value. Plot a graph of values of I against corresponding values of V, taking the latter along X-axis. I and V in reverse direction may be treated as negative values for this graph.

2.15 (Experiment): To read the values of carbon resistors by using the colour code and check with those found by a multimeter. Thus to study laws of combining resistances in series and parallel, using a multimeter.

Apparatus: 10 carbon resistors of different values, multimeter with two or three different scales for resistance measurement

Procedure. Take 10 carbon resistors of different values from 100Ω upto 1 MΩ. Label them $R_1, R_2, ... R_9, R_{10}$. Make out the values of all the ten resistors by the use of colour code (for ready reference see guidance table provided in the appendix 3). List up the values so obtained in the table (A) of observations, p. 52.

Take a multimeter. Set it at highest range of resistance measurement. Short circuit the terminals and adjust the zero ohm deflection (full scale deflection) by the adjustment provided. Find the value for larger resistances on the range. If for a resistor the reading is less than 1/5th of the mid-scale value, use the next smaller range. Thus measure each resistor by selecting the proper scale. List the values obtained with the meter against the values obtained by the colour code. Is there any difference in the two values? If yes, find the difference and find what percentage it is of the colour code value. What, do you think, is the reason for this difference, (tolerance of resistor/error in multimeter measurement/resistance of loose contacts/friction in movement of needle)?

(b) Make three sets of two resistances in series. Calculate the combination resistance (R_s) for each set, on the basis of the multimeter values of resistances in it, using the for-

mula $R_s = R_1 + R_2$

Tabulate the values so found for each combination in table (B). Find the value of resistance for each combination by using multimeter and selecting the proper scale. Also tabulate that value in the appropriate column. Compare the two values for each combination of resistances. Repeat the same process by making three sets of two resistances in parallel. Calculate the combination resistance (R_p) for each set using the formula $1/R_p = 1/R_1 + 1/R_2$. Tabulate the calculated and measured values of R_p in table (C)

Note. 1. It is necessary to learn proper use of the multimeter, before handling it. This needs to be done by consulting your teacher or using the instructional manual of the multimeter. To practice proper use of the multimeter is one of the objectives of this experiment

2 The value of resistance found with the help of a multimeter is not the accurate value. You must get familiar with the magnitude of error in its measurements.

2.16 (Experiment): To determine resistance and sensitivity of a galvanometer by half deflection method and convert it to an ammeter and voltmeter, say of range 0.5A and 5V respectively.

Apparatus. The galvanometer, a fully (but not freshly) charged lead accumulator of known emf (6 volt), two resistance boxes (range 10,000 ohm and 50 ohm the range of letter one being slightly larger than resistance of galvanometer), two plug keys, reversing keys, constantan wire of known resistance per unit length, a standard 10 ohm resistance.

Method· (a) Measuring Resistance and Current Sensitivity

Connect the circuit as shown in Figure 2.23. R_1 is the resistance box of ranges 10000Ω. Its function is to pass a current in the galvano-

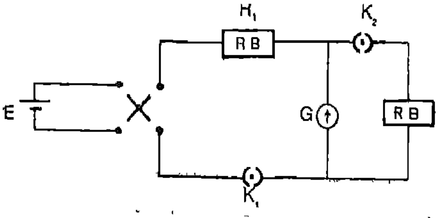


Fig. 2.23

meter so as to obtain a deflection within its range with K_2 open. The f.s.d. [2] of the galvanometer is usually marked on it and is good enough to serve as a rough guide. Make a resistance R_1 which gives a deflection θ (scale division), not less than 1/3rd of the full scale, and record R_1 and θ in Table 1 under observations.

Next close the key K_2 and adjust the value of resistance in the resistance box R_2, so that the deflection of the galvanometer becomes θ/2. Then the resistance R_2 equals G, the resistance of galvanometer, because half of the current passing through R_1 is shared by R_2 and half by the galvanometer. It is noteworthy that R_1 is so large compared to R_2 or G that opening or closing the key K_2 makes insignificant difference in the current passing through R_1.

You may find it rather time consuming to

[2] f s d, i e full scale production (current required for) is usually marked so that the user can take precaution not to pass too heavy a current in the galvanometer, lest it may get damaged

Observations (A) Value of the Resistors

Resistor	*Value by colour code and the tolerance* (ohm)	*Value found by using multimeter* (ohm)	*Percentage difference*
R_1			
R_2			

R_9			
R_{10}			

(B) Series Combinations of Resistors

Resistors in series, measured values		*R_s by calculation (ohm)*	*R_s by multimeter (ohm)*
R_1 (ohm)	*R_2(ohm)*		

(C) Parallel Combinations of Resistors

Resistors in parallel, measured values		*R_p by calculation (ohm)*	*R_p by multimeter (ohm)*
R_1 (ohm)	*R_2(ohm)*		

change R_2 several times and observe the deflection, until it becomes $\theta/2$, as best as you can observe it. You may better make any value of R_2 which gives a deflection θ', roughly equal to $\theta/2$. Record R_2 and θ'. Then

$$G = \frac{\theta\ \theta'}{\theta'} R_2$$

If C is the current sensitivity of the galvanometer then with K_2 open, the current passing through it is

$$C\theta = E/R_1$$
$$C = E/R_1\theta$$

Thus calculate the resistance G and the current sensitivity C of the galvanometer.

Repeat these observations and calculations by reversing the current. Take at least three values of deflection θ, between full scale to 1/3 of full scale. Thus you get at least 6 results for C and G. Find their means.

(b) Conversion to an Ammeter

Suppose you desire to convert it to an ammeter of f.s.d current equal to I (i.e. range I) Referring to Fig. 2.24(a) you connect a shunt, S, across its terminals for this purpose. Then a current I from the cell is divided into two branches, Current Cn flows in the galvanometer to show full scale deflection and I-Cn flows in the shunt.

$\therefore$ P.D across the galvanometer $= (I\text{-}Cn)\ S$
$= G\ Cn$

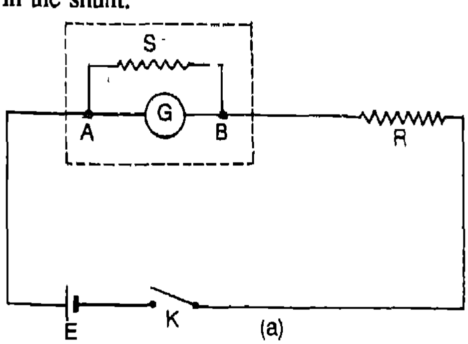
$$\text{or } \left(\frac{I}{Cn} - 1\right)S = G$$

$$\text{or } S = \frac{G}{\frac{I}{Cn} - 1}$$

Thus calculate the value of S and take a length of constantan wire that will make this resistance. Connect this shunt across the galvanometer to make the desired ammeter To check up its accuracy make connections as shown in Fig 2.24(a), using the resistance box of range 50 ohm for the resistance R. For various values of R observe the current in your ammeter. Compare your observations with calculated values E/R (neglecting resistance of the ammeter and internal resistance of lead accumulator).

(c) Conversion to Voltmeter

Now you want to convert it to a voltmeter of f.s.d. voltage equal to V (i.e. range V). Referring to figure 2.24(b), you connect a series resistance R for this purpose. Then a voltage V across terminals A and B passes a current Cn in the resistance $(R+G)$ to give full scale deflection in the galvanometer, thus



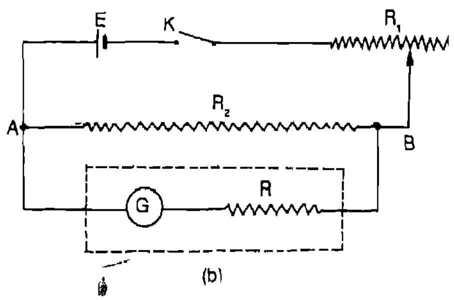


Fig. 2.24 *(a) A galvanometer with a suitable shunt connected in parallel with it makes an ammeter, (b) A galvanometer with a suitable series resistor makes a voltmeter.*

$$V = Cn\ (R + G)$$

$$R = \frac{V}{Cn} - G$$

Thus calculate the values of R Make this resistance in the resistance box of range 10,000 ohm, and connect it in series with the galvanometer, to make the desired voltmeter To check up its accuracy, connect circuit as shown in figure 2.24(b). Use the standard 10 ohm resistance for R_2 and resistance box of 50 ohm range for the variable resistor R_1, to make the potential divider. For various values of R_1, observe the voltage across AB. Compare your observations with calculated values, $ER_2/(R_1 + R_2)$, neglecting internal resistance of lead accumulator and treating the resistance of voltmeter $(R + G)$ to be very large.

Observations

Table 1 Resistance and Current Sensitivity

The emf, E, of the accumulator =

S.No	R_1 (ohm)	R_2 (ohm)	θ, with K_2 open	θ', with K_2 closed	$C = E/R_1\theta$ (mA/div)	$G = \frac{\theta - \theta'}{\theta'} R_2$ (ohm)

Mean C =
Mean G =

Table 2. Conversion to ammeter

No. of scale division in the galvanometer scale, n =

Desired range of ammeter to be made, I =

$$\text{Shunt required} = \frac{G}{\frac{I}{Cn} - 1} =$$

S.No	R (Ω)	Current observed (A)	Calculated value E/R (A)

Table 3. Convertion to voltmeter

Desired range of voltmeter to be made, V =

Series resistance needed = $\frac{V}{Cn} - G$ =

S.No	R_1 (Ω)	R_2 (Ω)	Observed P.D. (V)	Calculated value $ER_2 (R_1 + R_2)$ (V)

Notes 1. A laboratory galvanometer has 25 or 30 divisions in the scale towards right and left of zero mark. To find its resistance, if you have taken θ = 10 div and θ' = 5 div and taken readings to nearest full division, error in measuring θ and θ' is of the order of ± 0.5 division, i.e. about 10%.

2. If your instrument is of good quality, i.e. friction in its jewelled bearings is quite small and scale is accurate, you can try observing θ and θ' to $\frac{1}{10}$ th of a scale division by judgement, i.e. to first decimal place. Though this decimal place is insignificant, chances are that your error will reduce to about 2%, depending on the accuracy of your judgement.

3. To check up if friction in your instrument is small enough measure θ in the same setting 5 to 10 times. If each time, the needle comes to exactly same point on the scale, friction in your instrument is small enough.

TOPIC III THERMAL EFFECTS OF ELECTRIC CURRENT

2.17 (Demonstration): To demonstrate that (a) an electric current passing through a resistance wire produces heat, and (b) heat produced depends on the current flowing through the wire and its resistance.

Take a medium size drawing board, about 50 cm long. Fix two wires (thick AB of 28 SWG and thin CD of 32 SWG) of constantan having same length, say 120 cm. Fixing of wires may be done with the help of four drawing pins for each wire, as shown in Fig. 2.25. Take a charged

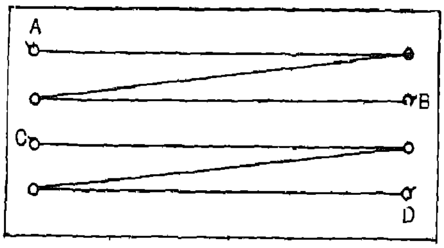


Fig. 2.25 *Fixing two long resistance wires on a drawing board*

2V lead acid cell, a plug key and some connecting wires. Two of these connecting wires are fitted with crocodile clips. Make the connections to pass electric current through the wire AB (thicker wire), as shown in Fig.2.26. Before

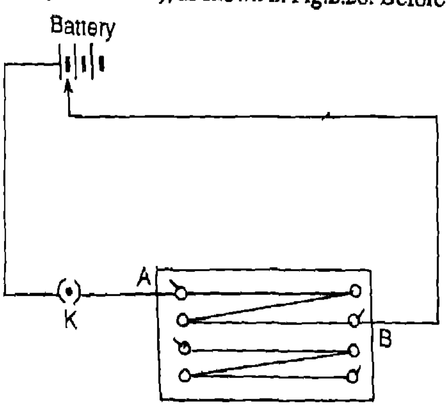


Fig. 2.26 *Demonstration of heating effect of electric current*

plugging the key, touch the wire with your finger tips, to have a feel of its temperature. Pass an electric current and after, say, about half a minute feel the wire by touching it with your finger tips again. Do you find the wire to have become warm?

For part (b) of the demonstration, connect an ammeter in series in the above circuit, as shown in Fig. 2.27. Plug the key, note the current flow-

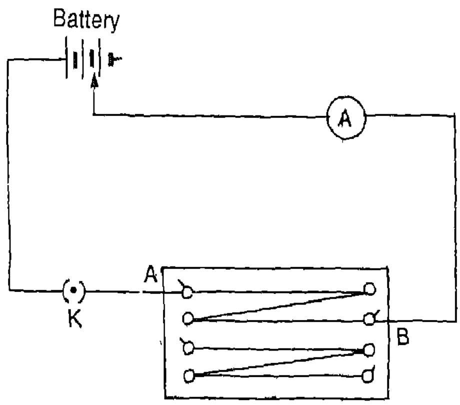


Fig. 2.27 *Circuit for demonstrating the factors on which heat produced in a conductor by the passage of electric current depends.*

ing in the circuit as indicated by the ammeter, record it and feel the wire with fingertips after 30 seconds. In order to increase current, let the e.m.f. of two cells be applied in the circuit. Connect another similar cell in series with the previous cell and again plug the key to let the current flow. After about the same duration of time (30 seconds) again note the current indicated by the ammeter, and feel the wire again at the same place, with your finger tips. Does the wire feel warmer with increased current flowing in it? By detailed experimentation it has been found that the heat produced is proportional to square of the current flowing through the wire.

Next, connect the crocodile clips at the ends

of thin wire CD This wire has greater resistance, as it has a smaller diameter compared to the thick wire AB and is of the same length. Pass current through this wire and after 30 seconds feel the wire with your finger tips. Now connect the crocodile clips with the ends of the wire AB (thicker). Again pass the current of same value and after about 30 seconds feel the wire with your finger tips (with thicker wire AB, a rheostat has to be added in the circuit and its resistance adjusted to get the same current). Do you find that the wire of higher resistance (thinner wire) gets warmer for the same current passing through the two wires. By detailed experimentation it has been found that the heat produced in a conducting wire is proportional to its resistance.

Notes: 1 Be cautious while feeling the wire with finger tips lest you burn the tips, specially when passing more current in the wire.

2. You can easily study quantitatively the dependence of heat produced on current (as a laboratory experiment). Use a Joules' calorimeter in which there is a heating coil through which current can be passed for heating water in it and rise of temperature can be noted by a thermometer. Pass currents I_1 and I_2 in turn, for same duration of time. In each case take same amount of water at same initial temperature in the calorimeter with the help of a measuring cylinder and note the temperature rises t_1 and t_2 respectively. Do you find that $t_1/t_2 = I_1^2/I_2^2$?

2.18 (Demonstration): To demonstrate (a) the use of an improvised fuse that melts with the flow of a certain current through it, and (b) different kinds of fuse used in everyday life.

(a) Demonstration of a Fuse

Take a small piece of suitable fuse wire (say 5A rating) and fix it across the improvised open type fuse (Appendix 4). Connect this electric fuse in series with a 6V lead acid battery, a 6V (18 watt or 24 watt) electric bulb (fixed in a

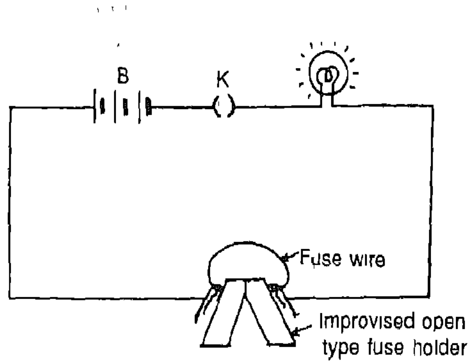


Fig. 2.28 *Circuit to demonstrate the working of a fuse*

holder), and a plug key as shown in Fig. 2.28 Plug the key and see if the bulb glows Observe the fuse wire. See, if it remains unaffected. Unplug the key to break the circuit Short-circuit the bulb by joining its terminals with a thick copper wire. Again plug the key for a short duration, the bulb would not glow this time. Observe the fuse wire snap quickly?

(b) Various kinds of fuses

For part (b) of the demonstration collect different types of fuses (i) used for different electrical appliances like a television set (ii) those used in the mains for the light circuit (5A) and (iii) for the power supply circuit (15A). Observe these and record your findings about the wire thickness.

Take a switch board used with the electric mains. This switch board should have a fuse socket a bulb holder (with a 100 watt, 230V electric bulb) and a switch in series with the fuse. It should also have a socket with the switch for connecting separately an electric appliance, say an electric heater in series with

the fuse. Fix up a 5A fuse wire in the socket for the fuse before plugging the switch board to the mains. Switch the electric bulb on (by using the switch provided on the switch board). The bulb would glow. Observe the fuse wire. Is it intact? Why? Switch off the bulb and unplug the board from the electric mains

Take a single strand of copper wire from the common flexible cable used as lead with a table lamp and replace it in the fuse socket Again plug the board with the mains and switch the bulb on. Does the bulb glow and keep glowing now? Unplug the board and see the effect on the improvised fuse wire. Does it change in colour? Next, connect an electric heater (1500W or 2000 W, 230V), to the board Plug on the board to the electric mains. Switch on the heater. Does the improvised fuse blow off now? Unplug the board from the mains and observe the fuse. Do you find it to have melted partly? (i.e. a small length of it).

Questions. 1. Why should electric current not be passed for a long duration in the circuit used in the above experiment after the 6V bulb has been short circuit?

2. Why is a TV cartridge fuse wire provided in a small glass tube?

3. What sort of fuse should be used so that it does not blow off when an electric heater is connected in series with it?

Note: In case you have not made the improvised open type fuse holder (Fig. 2.21), just hold the fuse wire ends in two crocodile clips. The open type fuse holder described in appendix 4, only makes a better demonstration.

TOPIC IV. THERMO-ELECTRIC EFFECT

2.19 Demonstration: To demonstrate that a pair of junctions of two wires of dissimilar metals or alloys at different temperatures produces an e.m.f. (Seebeck effect)

Make a thermocouple by joining two long copper leads, to the ends of a stout iron wire. The ends are first thoroughly cleaned and then twisted together. The junction to be heated is tied to the bulb of a thermometer which reads upto 360°C, and is embedded in a stand bath made by placing a large crucible full of sand on a burner. The thermometer is supported in a stand.

The other end is kept at 0°C by immersing it in a mixture of ice and water. A screen of wood stops the heat of burner from reaching the cold junction. The circuit is completed through a sensitive galvanometer (Fig. 2.29)

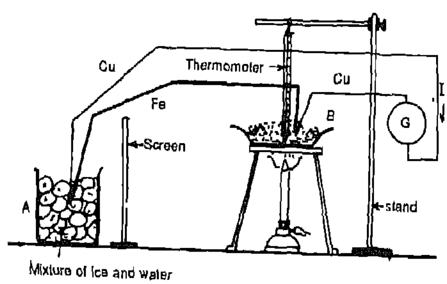


Fig. 2.29 *Circuit to demonstrate the thermo emf generated by a thermocouple*

The difference of temperature between the two junctions gives rise to an e.m.f. due to which a current passes in the circuit and deflects the needle of the galvanometer.

Note: 1. In this experiment, the galvanometer functions as a microvoltmeter because its resistance is very high compared to that of the thermocouple. It is essential to use a sensitive galvanometer otherwise the thermo e.m.f generated may not be indicated. A sensitivity of about 25μV per division of scale is necessary. A typical galvanometer with, taut-suspension

movement may have this sensitivity and is free from friction, which always exists in the pivoted type movement Electronic digital multimeter can also be used for this experiment A typical electronic digital multimeter may have various D.C voltage ranges from 100 μV to 1000 V.

2 It is advisable to make thermocouples with various combinations and show that any combination of two dissimilar metals or alloys produces thermo-electric e.m f Table 8 in data section gives the thermo e.m.f produced in μV for various combinations.

2.20 (Activity): (a) Make a sensitive thermopile and use it. (b) Observe the Peltier effect.

(a) *Making a Thermopile*

Paste a millimeter graph paper on a thick cardboard sheet 15 cm x 15 cm. Over an area of 13 cm x 13 cm of the graph sheet, prick a matrix of 14 x 14 holes by a sewing needle say of 28 SWG. Cut out 100 pieces of, constantan wire of 28 SWG (same diameter as the needle) all of equal length, say 7 cm Similarly cut 100 pieces of copper wire of same gauge and length.

Now, in the 196 holes of the matrix insert alternately the pieces of copper and constantan keeping half the length of each piece below the cardboard and half above it, as shown in Fig.2.30. In this figure dots (.) represent copper wires and circles (o) represent constantan wires.

In the column AB of 14 wires twist about 5 mm length of upper ends of (1,2) (3,4) ... (13,14) together and about 5 mm length of lower ends of (2,3) (4,5) (6,7)... (12,13). Repeat this process in all the columns With the help of a fine tip 10W soldering iron, solder the twisted ends so as to reduce contact resistance.

Having made these joints numbering 13 x 14 = 182, you have 14 columns of 7 thermocouples each. You are to join these 14 columns in series. In the first row, AD, join the lower ends of

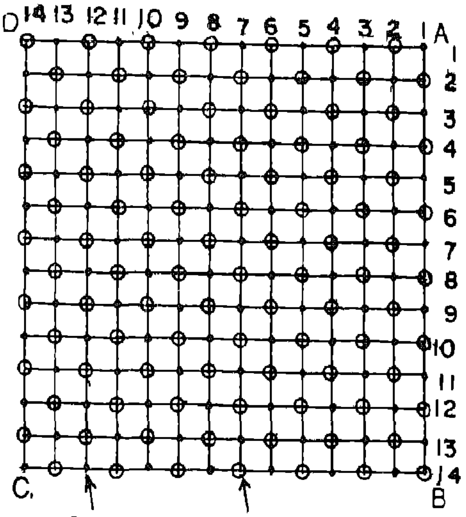


Fig. 2.30

wires (2,3) (4,5) .. (12,13). Then in the last row, BC, join the lower ends of wires (1,2), (3,4) .. (13,14). Now solder stout copper leads to lower ends of wires 1 and 14 in the first row. With these joints numbering $13 \times 14 + 13 + 2 = 197$ you have 98 upper junctions 98 lower junctions, which are all in series.

Now you have the 98 thermocouples joined in series in which the first wire at corner A is of copper and last wire at corner D is of constantan with a copper lead at its lower end, which is also the cold junction of last thermocouple. This [illegible] own with lower [illegible] surface of an [illegible] the leads to a moving coil galvanometer. (Fig 2.31).

Rub your hands together briskly to warm up their surface. Touch your hands on the matrix of upper ends. The small rise of temperature

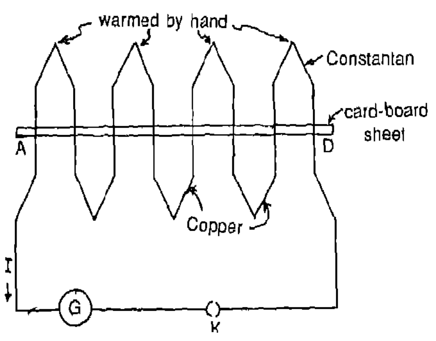


Fig 2.31

produces thermo e.m.f. at each junction. Total e.m.f generated in the circuit is the sum of all the small e.m.f.'s generated in the 98 thermocouples and is detected by the galvanometer *Note:* Using this principle of connecting thermocouples in series, packed in a small space and by using a mirror to focus radiation from a distance source, so sensitive instruments can be made which can measure radiation coming from individual stars.

(b) Peltier Effect

To observe the Peltier effect, you want to pas

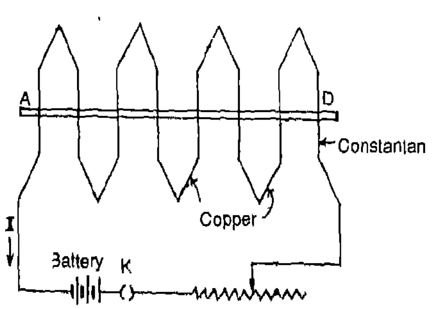


Fig. 2.32 *Circuit for observing the Peltier effect by using a thermopile*

a current through the thermopile and observe that one type of junctions get heated up and the other type cools down Connect the thermopile you have made to a lead accumulator, through a key, a rheostat and ammeter (Fig. 2.32). Check up that battery terminals are so connected that it passes current in the same direction in which current had passed by making upper junctions warm. Pass a current of about 100mA in the circuit so that resistive heating of the wires is quite small. After about one minute, feel the matrix of upper junctions and then, by the same hand, the matrix of the lower junctions. Do you feel that upper matrix is cooler then the lower one?

Next, reverse the terminals of the battery. After some time, when temperatures of the upper matrix and the lower matrix become equal to room temperatures pass the current. After about 1 minute again feel the two matrices. Do you now feel that the upper matrix is warmer. This generation of heat at one set of junctions and absorption of heat at the other set of junction is called *Peltier effect*

Note 1 Clearly the Peltier effect occurs at each junction and thus occurs in a single thermocouple too. To observe this effect, use of thermopile has been suggested because in a thermoplie, total heat absorbed or generated is quite large and is easily observed.

2. Materials have now been developed in which the generated thermo-e.m.f. is quite large. Thus also generation of heat at one junction and absorption of heat at the other when current is supplied to it, is quite large. Thus these have been successfully used for (a) conversion of heat energy direct into d.c. electrical energy and (b) refrigerating a closed container by so putting a thermopile in one of the walls that passage of a d.c. current in it absorbs heat inside the box and generates heat outside the box, which is delivered to the warm surroundings.

This technology is, however, still at the research laboratory stage [2]

TOPIC V: FLOW OF CURRENT THROUGH ELECTROLYTES

2.21 (Demonstration): To demonstrate that a high resistance is offered by distilled water and a low resistance when sodium chloride is added to it.

Take two electrodes A and B (aluminium strips or plates hanging from a wooden rod by naked copper wires will do) and dip them in a beaker about half filled with distilled water (analytical reagent). Make a connection of the electrodes with a dry cell (1.5 volt) and a light emitting diode (LED), as per the circuit shown in Fig. 2.33. To start with, check if the LED

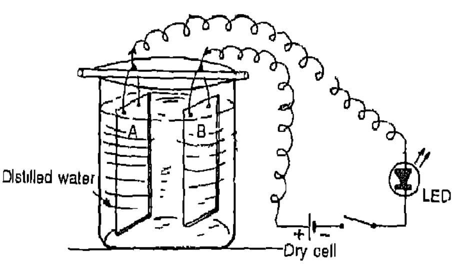


Fig. 2.33 *An arrangement to demonstrate the effect of adding salt on the electrical conductivity of distilled water*

has been connected properly in the circuit as it conducts electric current in one direction only. Its proper terminal has to be connected to the positive terminal of the cell to make it glow. For checking this, take the electrodes A and B out of water, touch them with each other for out of water, touch them with each other for a while and see that the LED glows. Next, leave A and B in the water and separate them with the maximum gap of water. Does the LED glow now?

Bring the two electrodes A and B nearer so as to leave a small gap of water. See if the LED glows? Add a pinch of common salt to the water while the plates are as far apart as when LED was not glowing. Does the LED glow now?

Draw the conclusions on the basis of your observations and record.

Notes: 1. If you replace the LED by a multimeter which has various ranges for measuring d.c. current, add salt to water in equal measured steps, then you can find concentration of salt in each case and also the resistance of the solution. Do not alter the position of the two plates during the experiment. Thus you can study how the resistance varies with concentration of salt.

2. In general, the resistivity of an electrolyte (solution of a salt whose molecules break up into anions and caitons) decreases with increasing concentration. This is due to the fact that as concentration increase, greater number of charge carrier (+ve and -ve ions) are available, which move in the electric field created between the two electrodes when a potential difference is applied between them.

3. Whereas in a metal wire the drift of only the negative charges (electrons) contributes to the flow of current, in case of an electrolyte the drift of negative ions as well as positive ions contribute to the flow of current. However the nature of motion of positive ions or negative ions, both, is similar to that of the small beeds in the mechanical analogue discussed in demonstration 2.4. It is a zig-zag motion coupled with a slow drift in the direction of the electric force.

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[2]Reference: *Journal of Electrical Engineering*, November 1984, p 94-95, article entitled New Materials: 11: Thermoelectric Conversion Materials.

TOPIC VI· CHEMICAL EFFECT OF ELECTRIC CURRENT

2.22 (Experiment). To determine the electrochemical equivalent of copper.

Appratus: Copper voltameter (with two copper plates as anodes and a central cathode (A simpler instrument merely with two plates, one as anode and the other as cathode can also be used), ammeter (0-3A), 6V-battery (or D.C. power supply), plug key, rheostat, connecting wires, emery paper, a sensitive balance, weight box, stop-watch/clock.

Procedure· Thoroughly clean the copper plates with emery paper and wash them in water. Place the plates in a jar containing copper sulphate solution of density 1.15 to which 1% of sulphuric acid has been added. Connect the two outer plates together and to the positive terminal of the battery. Connect the central plate (cathode) to the negative terminal of the battery. Put in the key and adjust the rheostat such that the current is of about 0.006 ampere per square centimetre of the cathode surface immersed in the solution (Fig. 2.34). After 4 or 5 minutes take out the central plate, wash it thoroughly in water, immerse it in methylated spirit or ether, and allow it to dry. Determine the mass of this plate accurately, because mass of copper that will be deposited on it will be far smaller than its mass

Now replace the plate in the circuit, allow the current (controlled by rheostat) to flow for about half an hour. Note the current after every two minutes and calculate its average value, I, for the entire time interval for which current is passed. Also measure this time interval t, by the stop-clock. Again take out the central plate, wash it thoroughly in water, immerse it in methylated spirit or ether, allow it to dry and determine its mass accurately. Calculate the increase in its mass, m, which is the mass of copper deposited.

Then calculate the electrochemical equivalent of copper i.e., mass of copper deposited by 1 coulomb of charge.

$$z = \frac{m}{It}$$

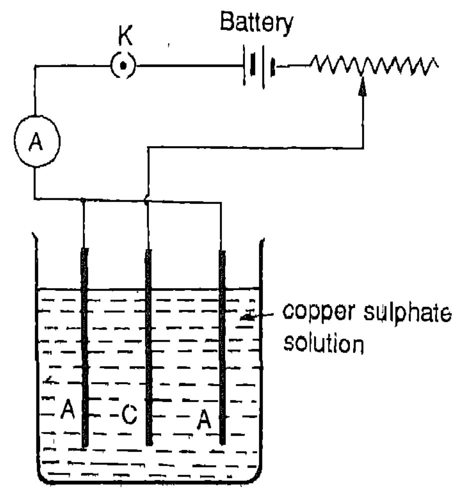


Fig. 2.34 *Circuit for determining the electro-chemical equivalent of copper*

Note: 1. One may ask the question why at all the first weighing is done after a 4 or 5 minute deposit of copper. The reason is that there is always a small error due to some moisture staying on the surface. In the process described above this error is reduced to a great extent. Any effort to quicken the drying process or to make the plate completely dry by hot air is likely to oxidise the deposited copper, thus making it a bit dark and adding the weight of oxygen which combines with surface layer of copper.

2. If electro-chemical equivalent of several elements is measured, this experiment leads to verification of Faraday's laws of electrolysis.

This may be taken up as an activity by interested students.

3 For detailed precautions about obtaining a good deposit, see experiment 2.24 (demonstration of electroplating).

2.23 (Experiment) : To find the ratio of masses deposited in two different voltameters connected in series and having different electrolytes.

Apparatus: One copper and one silver voltameter, ammeter (0-3A), 6 volt battery (or D.C. power supply), rheostat, connecting wires, fine-grain emery paper, a sensitive balance, weight box.

Procedure: Thoroughly clean the plates of both the voltameters with emery paper and wash them with clean water. Connect both the voltmeters in series and complete the circuit as shown in Fig 2.35.

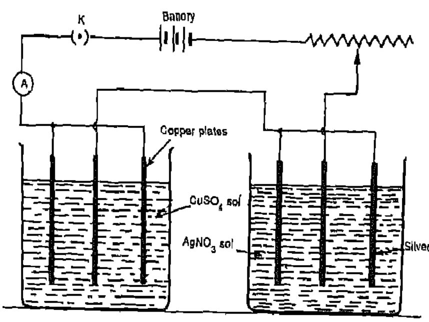


Fig. 2.35 *Circuit for finding the ratio of masses deposited in two different voltameters connected in series*

On closing the key K, the flow of current starts in the circuit, resulting in deposition of copper on copper plate in copper voltameter and silver on silver plate in the silver voltameter. Since the two voltameters are connected in series, the amount of current passing through both is same and it flows for same time.

Using the same procedure as in experiment 2.22 calculate the masses m_1 and m_2 deposited on the cathodes of the two voltameters during same time interval, by the same current.

Next see the table for the values of equivalent weight E_1 & E_2 of copper and silver and check whether the ratio of deposited masses is same as that of their equivalent weights i.e

$$\frac{m_1}{m_2} = \frac{E_1}{E_2}$$

Note All precautions that are to be taken in experiment 2.21 for getting a good deposit and correct mass of deposited metal, are applicable in this experiment also

2.24 (Demonstration): To demonstrate copper plating/nickel plating.

Note The complete process of electroplating is quite time-consuming. It may be taken up as a long activity (project) by interested students But a class demonstration in which plates are previously cleaned is advisable. In the class room the circuit may be made, current may be passed for about 10 minutes and then the small amount of deposit on the cathode which makes the portion of cathode inside electrolyte distinct from the rest may be shown to students

Procedure : In a copper voltameter or any vessel (which is not affected by dilute sulphuric acid) fill copper sulphate solution of density 1.15, to which 1% of sulphuric acid have been added The object to be electroplated is made the cathode, i e. it is connected to negative terminal of the D.C. supply The metal to be deposited (copper in this experiment) is in the form of two plates, one on each side of the cathode and is made the anode, i e it is connected to positive terminal. The copper ions in solution are positive ions, drift towards the cathode (so called *cations*) and get deposited on it. The sulphate ions are negative ions and move towards the anode (so called *anions*). After giving their charge to the anode, sulphate

ions combine with the metal of the anode to form copper sulphate which goes back into the solution Thus the strength of the solution is maintained. For nickel plating, prepare a saturated solution of nickel ammonium sulphate in water of 25°C Filter it and add a small quantity of sulphuric acid (Fig 2 36)

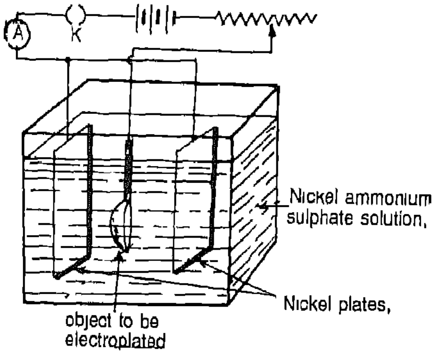


Fig. 2.36 *Circuit to demonstrate nickel plating.*

The object to be electroplated should be perfectly clean It is rubbed with fine emergy powder and even, somtimes, against a polishing wheel. To remove grease it may be dipped in hot solution of caustic potash, washed with water, dipped in dilute nitric acid and finally dipped in distilled water. During the process of cleaning and thereafter, the object should not be touched by hand, otherwise the grease from hands will spoil it.

The solution (called electrolyte) should be of proper strength. if it is too concentrated, it will give dark and spotted deposite. The plating will be brittle and will go off easily. On the other hand, if the solution is too diluted, the deposite will be not only slow but also not firm and adherent.

After cleaning the object to be electroplated and two plates of the metal to be deposited, suspend the former in the centre of the vessel and the latter on either sides of the former by copper wires. Arrange the circuit as shown in Fig. 2.36. Adjust the rheostat so that the current is of about 0.006 ampere per square centimeter of the area of the cathode Importance of correct strength of current should not be underestimated. An error on the lower side is safer A weak current gives a fine-grained and firmly adherent deposit, while a strong current gives a spongy and brittle deposit. Usually a 6-volt battery (or D.C. power supply) is enough to pass this current

Pass the current for one or two hours, according to thickness of deposit desired. Stir the solution gently during the experiment. It ensures uniform thickness of the deposited layer on the cathode. The electroplated plate is then washed with hot water, dried and polished by rubbing briskly by a dry clean cloth (or buffed).

2.25 (Demonstration): To demonstrate the working of (a) Voltaic cell, (b) Leclanche cell, and (c) Daniel cell.

Theory: A primary cell, as you know from the textbook (Chapter IV) is a device for converting chemical energy into electrical energy. It consists of two different metals separated from each other by an electrolyte. The e.m.f. of a cell depends on the nature and concentration of the chemicals used, and their size affects only the internal resistance. You would set up the three primary cells.

(a) Demonstration of Voltaic Cell

Take a beaker of 250 ml capacity and fill it 3/4th with dilute sulphuric acid (molar solution). Next, take a clean plate of copper and one of zinc sheet, each 4 cm x 12 cm (about 1 mm thick) provided with a terminal to which is connected an insulated conducting wire. Stand the two plates leaning to the walls of the beaker. Measure its e.m.f. with the help of a high resis

tance voltmeter (range 0-3V) using the circuit shown in Fig. 2.37. Next, complete the circuit by connecting a torch lamp B, an ammeter of

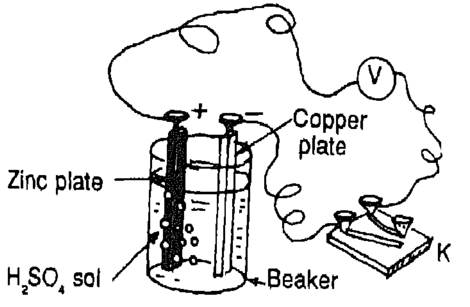


Fig. 2.37 *Circuit to demonstrate the emf of a simple Voltaic cell*

range 0-500 mA and a plug key in series with the two plates of the cell (Fig. 2.38). Close the plug key. Do you find the ammeter to give some

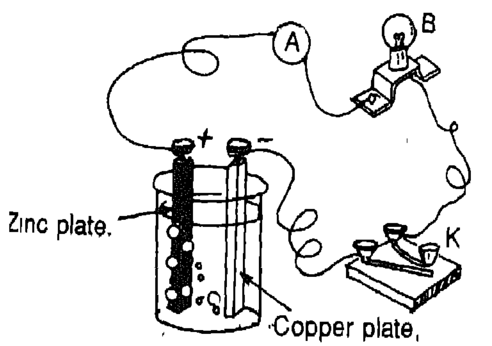


Fig. 2.38 *Circuit to demonstrate polarization in a simple voltaic cell.*

deflection even if the bulb does not glow? Observe if the current indicated by the ammeter starts falling in a few minutes. Observe carefully the copper plate. Do you find that small bulbs start collecting on its surface (this phenomenon is called *polarization*)? Clean this plate by taking it out of the electrolyte and put it back. Do you find in ammeter that the cell again gives the full current as when it was fresh?

(b) Demonstration of Leclanche Cell

For demonstration of Leclanche cell take the three components used to assemble it (amalgamated zinc rod, porous, pot, and glass jar), besides the ammonium chloride solution (Fig. 2.39). Assemble the cell and connect a volt-

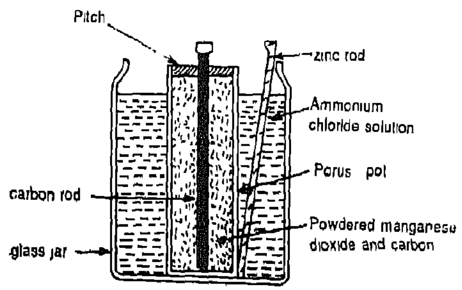


Fig. 2.39 *Construction of a Leclanche cell*

meter, of range 0-3V, to its terminals with a plug key in series (Fig. 2.37). Insert plug in the key to complete the circuit and record the e.m.f. indicated by voltmeter. Next, take a carbon rod taken out of a discarded porous pot of a Leclanche cell. Assemble another cell, similar to the volatic cell, using the carbon rod in place of the copper plate (and use dilute sulphuric acid as electrolyte). Check up by a high resistance voltmeter (range 0-3V) that its e.m.f. is same as that for the Leclanche cell. Complete the same circuit for this cell as well as the Leclanche cell, as was done for the voltaic cell to check whether it can supply a sustained current (Fig. 2.38). Plug the keys simultaneously and let the current flow for some time (say 3 minutes). Keep observing the deflection indi-

cated by the ammeters in the two circuits. Do you find that the current in case of one drops and in the other it remains more or less steady? Why is it so? Observe carefully the contents of a discarded porous pot. Can you think of the role played by it?

Measure the e.m.f. of a fresh dry cell using a high resistance voltmeter. Do you find it to be same as that for the Laclanche cell? Cut open a large discarded dry cell (Fig. 2.40), with the

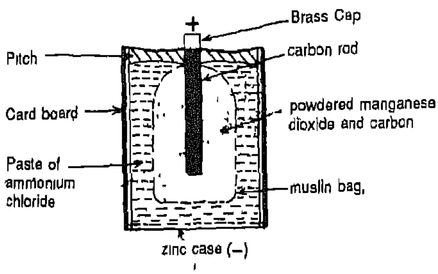


Fig 2.40 *Construction of a dry cell*

help of a junior hack-saw (15 cm blade). Observe its components and compare these with those of a Laclanche cell. Do you find it to be a modified Leclanche cell, which is portable?

You are advised to use the dry cells intermittently (by giving some rest-intervals). Can you think of a reason for this? Has the process of oxidising the hydrogen collected in the mixture of manganese dioxide and carbon, to do something with it?

(c) *Demonstration of a Daniel Cell*

Assemble Daniel cell by collecting its components: a specially designed copper vessel, a hollow porous pot with 5% solution of sulphuric acid in it and an amalgamated zinc rod. The copper vessel contains saturated solution of copper sulphate and crystals of copper sulphate

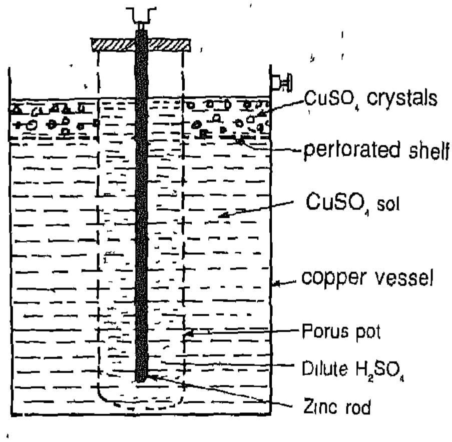


Fig. 2.41 *Construction of a Daniel Cell*

on a porus shelf immersed in the solution (Fig 2.41). Connect a voltmeter to its terminals, using the circuit of Fig. 2.37). Observe the deflection in the voltmeter and record e.m.f. of this cell. Is it same as that for Voltaic cell?

Next use the cell to complete the circuit of Fig. 2.38. Observe the deflection in the ammeter. Does it remain steady? How do you compare its performance with that of Voltaic cell?

2.26 (Demonstration): To show the working of a lead acid battery.

(i) Examine the lead grid taken out from an old lead acid battery.

(ii) Observe its low internal resistance, by connecting it through an ammeter (0-10A). Use a resistance of 1 Ohm in series for a 6V motor cycle battery, in order to prevent damage to the battery as also heating up of connection wires, which may cause a burn. The circuit should be completed for not more than one or two seconds. For this purpose use a tapping key in the circuit and not a plug

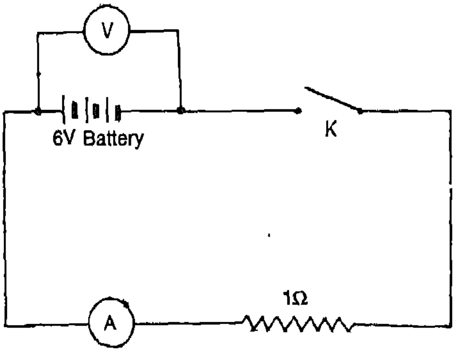


Fig. 2.42 *Circuit to demonstrate the low internal resistance of a lead acid battery.*

key. Observe a minute fall in the voltage of the battery, indicated by the voltmeter (Fig. 2 42), when the key is pressed Explain the necessity of never short circuiting it. (Some equipment like an ammeter of smaller range, etc. may get damaged by the heavy current produced and life of the accumulator itself is greatly reduced.)

(iii) It should be recharged when voltage of any cell in it falls to 1.85 volt, from the normal voltage of 2.0 volts. For this purpose it should be connected to battery charger, as shown in Fig. 2.43. The reactions during its use and during charging are as follows:-

Positive electrode

$$PbO_2 + 4H^+ + SO_4^{=} + 2e^- \underset{\text{charging}}{\overset{\text{using}}{\rightleftarrows}} PbSO_4 + 2\,H_2O$$

Negative electrode

$$Pb + SO_4 = \underset{\text{charging}}{\overset{\text{using}}{\rightleftarrows}} PbSO_4 + 2e^-$$

Thus, $PbSO_4$ is formed on both electrodes during use and an over-used cell is said to have

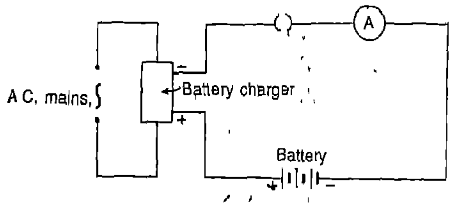


Fig. 2.43 *Circuit for charging a battery with the help of a battery charger.*

become "sulphated". Also, formation of water and consumption of sulphuric acid and consequent decrease in density of the acid takes place.

Since ordinary voltmeters may not measure voltage quite accurately, a voltage of 1.85V may be read as 1.9V Thus measuring e.m f of an acid accumulator is not the best method to test whether it needs recharging. Density of the acid inside, is a much better indicator. In a charged accumulator, it is 1.26 kg/l. When it falls to 1.20 kg/l, the accumulator needs to be recharged Measure density of acid inside the accumulator by the special hydrometer made for this purpose and infer the condition of that accumulator. The density should be measured only after "topping it up" with distilled water

(iv) Effect of over-charging a battery is loss of water by electrolysis and hence the need to check its water level continually and bring it up by adding distilled water. This process is sometimes referred to as "topping up" with distilled water.

(v) A 6-volt small lead acid battery used in photography has a system of beads built into it, which indicate the condition of the cell at a glance, by giving you an idea whether density of the acid inside has become too small. Thus this kind of battery is much easier to use and is quite good for currents upto 1A

(vi) Sulphuric acid for a new battery is made by pouring slowly the concentrated acid into distilled water, 3-times its volume. When this acid cools, it is filled in the

new lead acid battery and then the battery is charged overnight.

TOPIC VII. USE OF POTENTIOMETER

The Potentiometer · It consists of a long wire of uniform cross-section stretched between two brass strips A and B (Fig. 2.44). Lengths of

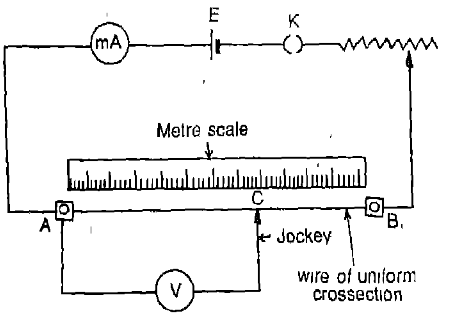


Fig. 2.44 *Circuit to study the fall of potential along a potentiometer wire. It can also be used to find the end cross-section of the potentiometer.*

1 metre, 2 m and 4 m are common. When the length is greater than 1 metre, it is divided into sections of 1 metre long each, which are connected in series, on a plane wooden board.

When a current is passed in the wire with the help of cell E, a potential difference is developed between A and B. Potential difference also exists between the point A and any point C on the wire, which is proportional to resistance of the portion AC of the wire. Since this resistance is proportional to length l, of the wire, AC, the potential difference V, between A and C is also proportional to l, and varies continuously along the wire. This fact is often referred to as the *principle of potentiometer*. You may like to check up this fact by connecting a voltmeter between A and C, measuring V and l and plotting a graph between them. It may, however, be mentioned that precision of any voltmeter is far less than that of the proportionality relation between V and l in a common potentiometer in a school laboratory.

The contact at the moving point C is made by a device, called *jockey*. It has a knife edge perpendicular to the wire which is lightly pressed down to make contact with the wire (Fig 2.45). A mark on the frame in which the

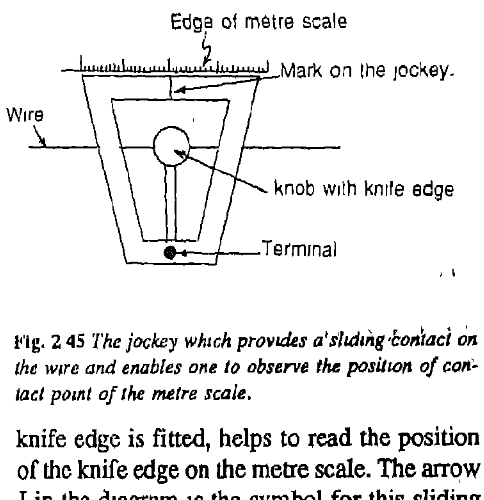


Fig. 2.45 *The jockey which provides a sliding contact on the wire and enables one to observe the position of contact point of the metre scale.*

knife edge is fitted, helps to read the position of the knife edge on the metre scale. The arrow J in the diagram is the symbol for this sliding contact (i.e. the jockey).

The potentiometer is essentially a device which converts the potential difference at the terminals of a cell into a continuously variable potential difference. Also this potential difference is accurately proportional to length of the wire AC. We may either operate another instrument by this variable potential difference or compare an unknown potential difference with it. For either function, the current in the wire AB (Fig 2.44) should remain constant throughout the experiment. This implies, that

the e.m.f. of the cell or accumulator E, which supplies this current should not change during the experiment. To ensure this, the current should be drawn intermittently, for short intervals of time. As an added precaution, it may be monitored by a sensitive ammeter (or milli-ammeter) and re-adjusted whenever necessary, with the help of a rheostat (Fig. 2.44).

End Correction of Potentiometer: Obviously for $l = 0$, you expect the potential difference between A and C to be zero, as the two points coincide. It may not happen, however, in some instruments. If the end A of the wire and lower surface of the strip A are not quite clean, a contact resistance may develop between the strip and this end of the wire. Measure potential difference between A and C, for position of C close to A, (say, within 10 cm of the end A) with the help of a milli-voltmeter. Then plot a full scale graph between V and l, i.e. a distance of 1 cm along l-axis in the graph represents 1 cm length of the wire. You get a straight line, but it may make a negative intercept on the l-axis. This negative intecept gives the end correction at end A, i.e. the length of wire which will have same resistance, as the contact resistance at end A.

2.27 (Experiment) : To compare the e.m.f.'s of two cells by using a potentiometer

Apparatus: Potentiometer with jockey, plug key, source of D.C supply, rheostat, a Leclanche cell, a Daniel cell, a two-way key, galvanometer and resistance box (or a resistance of 10000 Ω and another plug key to shunt it and thus make it zero when desired). The e.m.f. of the source of D.C. supply must be more than either of the cells.

Procedure; First connect the circuit as shown in Fig. 2.44 and find the end correction at end A of the instrument. Use the galvanometer itself as a millivoltmeter for it. There is no need to know the p.d. readings in mV, and it may be measured in an arbitrary unit, represented by a scale division of galvanometer.

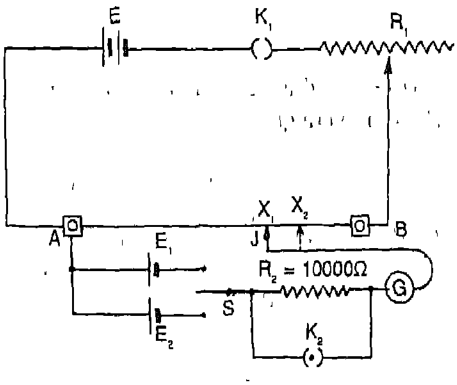


Fig 2.46 *Circuit for comparison of emf of two cells*

Next, connect up the circuit as shown in Fig. 2.46, E_1 and E_2 are the two cells whose e.m.f.'s are to be compared, say a Leclanche cell and a Daniel cell. K_1 is a 2-way key so arranged that the cell E_1 and E_2 can be connected to the galvanometer easily without any troublesome disconnections. Two simple plug keys can also be arranged to serve the same purpose. The galvanometer G is connected to sliding contact J through a resistance box, R_2 of 10000 Ω (or a single resistance of 10000 Ω) shunted by key K_2

First set the rheostat R_1 at zero resistance and a high resistance R_2 in the resistance box for safety of galvanometer. Test the circuit as follows: with the galvanometer connected to E_1, touch near each end of the potentiometer wire in turn with the jockey and the galvanometer should show opposite deflections. Repeat the same process with E_2. If opposite deflections are not obtained with both cells, check that positive poles of all three cells E, E_1 and E_2 are connected to same point A on the potentiometer. (It obviously makes no difference if negative poles of all three cells are connected

to A).

Now with E_1 connected to the galvanometer, obtain the null point X_1 on the wire, i.e. with the jockey connected at X_1 there is no deflection in the galvanometer. First find approximate position of X_1 with a high resistance R_2 in series with galvanometer and then the accurate position with R_2 shunted by K_2. Note the position of X_2 on the meter scale, which gives the length AX_1 (= l_1). Similarly find null point X_2 with E_2 connected to the galvanometer and measure the length AX_2 (= l_2).

Change the resistance in rheostat R_1 a little so as to change the current in the potentiometer wire and thus the potential difference across AB. In same manner as described above, obtain a new set of values of l_1 and l_2. Since the fall of potential along the wire is proportional to its length, for any set of values of l_1 and l_2,

$\frac{E_1}{E_2} = \frac{l_1}{l_2}$ where E_1 and E_2 respectively are e.m.f.'s of cells E_1 and E_2. If you are required to make an accurate comparison of E_1 and E_2 then find the end correction of end A of the wire, as described earlier, and add it to both l_1 and l_2

Observations:

(1) *Measuring the end correction*:

Length of wire A.C. l (cm)
P.d. across AC, V (Scale division)
From V versus l graph, end correction at end A = ______ cm

Note: It may be noted that while finding the null points, no current is drawn from the cells E_1 and E_2. Thus p.d. across l_1 and l_2 are equal

(2) *Comparison of E_1 and E_2*

S.No of rheostat setting	Position of null point		Corrected value of		
	l_1 (cm)	l_2 (cm)	l_1 (cm)	l_2 (cm)	$\frac{E_1}{E_2} = \frac{l_1}{l_2}$

to their true e.m.f.'s. In contrast to this, if we attempt to measure their e.m.f.'s by a voltmeter, some current is drawn by the voltmeter and what we measure is something less than their true e.m.f.'s.

2.28 (Experiment): To find the internal resistance of a cell by potentiometer.

Apparatus: Potentiometer with jockey, a dry cell whose internal resistance is to be measured, three plug keys, source of D.C. supply, a resistance box, a 10000 ohm resistance.

Procedure The procedure is same as in experiment 2.26. The only difference is that instead of two cells E_1 and E_2 of experiment 2.26, we connect the dry cell D, and shunt it by resistance box R_3 through plug key K_3 (Fig. 2.47).

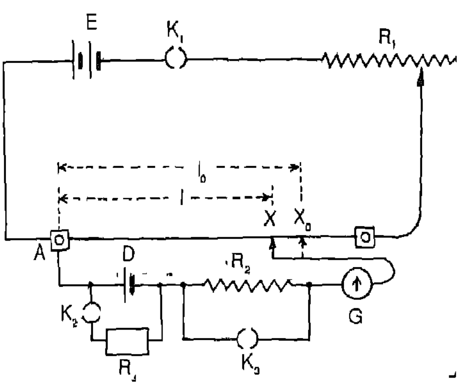


Fig. 2.47 *Circuit for finding the internal resistance of a cell*

The first null point X_0 is obtained with K_3 open and thus when no current is drawn from the cell D. Then length of the wire AX_0 $(=l_0)$ is noted

Now a null point X is obtained with K_3 closed and some resistance R_3 in the resistance box and length of the wire AX $(=l)$ is noted. Without changing the resistance of rheostat, R_1, find several null points with various resistances R_3. Each time note the resistance R_3, along with the length l of potentiometer wire A to the concerned null point

The first length l_0 corresponds to e.m.f. of the cell D when no current is drawn. The subsequent lengths are smaller because p.d. across the terminals of the cell is reduced when some current is drawn from it. The e.m.f. of the cell D derives a current through total circuit resistance $r + R_3$ where r is the internal resistance of cell D. Thus p.d. across its terminals (or at the terminals of R_3) is the fraction $R_3/(r + R_3)$ of the e.m.f. of the cell D.

$$\therefore\ l = l_0 \frac{R_3}{r + R_3}$$

$$\text{or } 1 + \frac{r}{R_3} = \frac{l_0}{l}$$

$$\text{or } \frac{1}{R_3} = \frac{l_0}{lr} - \frac{1}{r}$$

Plot a graph between $1/R_3$ and $1/l$, taking $1/l$ along the X-axis. Draw a straight line as close to the points plotted as you can. The negative intercept on the Y-axis, along which $\frac{1}{R_3}$ is taken, gives the values of $\frac{I}{r}$ (Fig. 2.48) Thus calculate r.

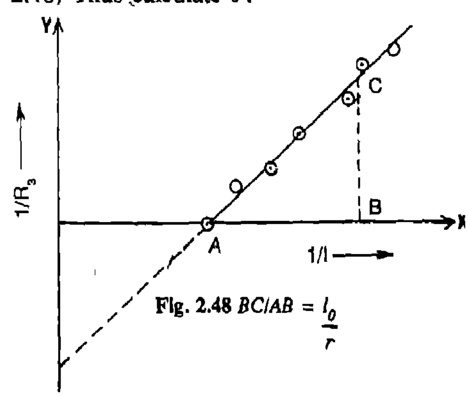


Fig. 2.48 $BC/AB = \frac{l_0}{r}$

Question: (i) While drawing the straight line graph will you treat the point corresponding to first reading when $R_3 = \infty$ and position of null point is l_0 as a point on the graph, like the points corresponding to subsequent readings?

(ii) You know the end correction at the end A of the wire. Is it of any significant use in your calculation? (No, because the relationship between r and R_3 can also be written as $R_1 = R_3 (l_0-l)/l$ End connection does not affect the numerator of this formula and its effect on the denominator is quite small, as l is quite large).

Notes: 1. As stated earlier, the key K_1 should be closed for short intervals only during which null point is being located.

2. Small current (upto 300mA) should be drawn from the dry cell D, for short intervals only, so that e.m.f. and internal resistance do not change during the experiment Thus do not make a resistance less than 5Ω in resistance box R_3 (Fig. 2.47), as the e m.f of a dry cell is 1.5 volt.

2.29 (Experiment): To compare accurately two resistances of approximately equal value, using a potentiometer.

Apparatus· Potentiometer with jockey, two sources of D C. (accumulators), two plug keys, two rheostats, sensitive galvanometer, two resistance R_1 and R_2 which are to be compared (e.g. one may be a suspended standard resistance and the other a trustworthy standard resistance of same value)

Procedure Connect the circuit as shown in Fig. 2 49. The points A and X are connected to the resistances R_1 and R_2, through a double pole double throw switch Thus potentiometer measures the potential differences across R_1 when this switch connects to A to C and D to J Similarly, it measures the potential difference across R_2 when this switch connects to A to D and J to E.

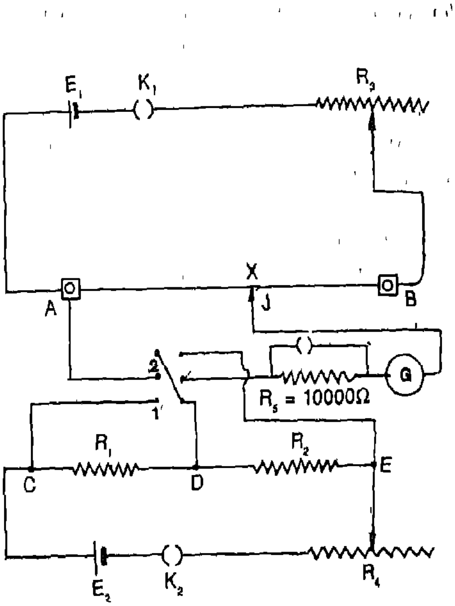


Fig 2.49 *Circuit for accurate comparison of two nearly equal resistances R_1 and R_2*

The resistance R_1 and R_2 are connected to series through key K_2 to accumulator E_2 and rheostat R_4. Thus exactly the same current passes through both the resistances when key K_2 is closed. Hence

$$\frac{R_1}{R_2} = \frac{\text{P.D. across } R_1}{\text{P.D. across } R_2}$$

For maximum sensitivity, the p.d. across the potentiometer wire AB is adjusted to be slightly more than the p.d. across the larger of the two resistances R_1 and R_2. Thus the null points for each of the resistances R_1 and R_2 will be close to the end B of the potentiometer wire.

Rest of the procedure is similar to experiment 2.26 (comparing e.m.f.'s of two cells) Null point X_1 is obtained for the P.D. across resistance R_1 the length AX_1 $(=l_1)$ is measured. Then by changing the position of double pole-double throw switch null point X_2 is obtained

for the P.D. across resistance R_2 and length AX_2 ($=l_2$) is measured. Then $\frac{R_1}{R_2} = \frac{l_1}{l_2}$, since l_1 and l_2 differ only little, the end correction does not significantly affect the result as in experiment 2.28.

Note 1. If the potentiometer wire is of accurately uniform cross-section any two resistances can be accurately compared by this method The end correction at end A must, then, be added to l_1 as well as to l_2.

2.30 (Experiment): To study the variation of the thermo-e.m.f. generated in copper-iron thermo-couple with temperature using a potentiometer.

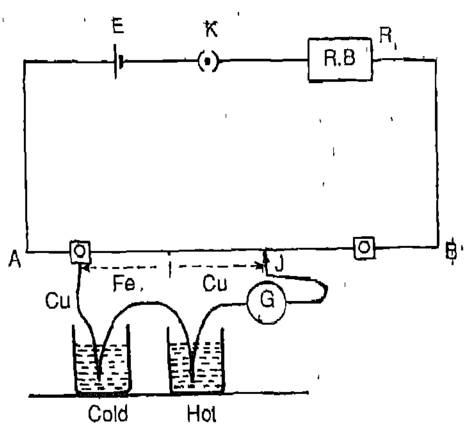


Fig. 2.50 *Circuit for measuring the thermo emf generated by a thermo-couple*

Apparatus: Potentiometer, storage cell plug key, resistance box (upto 5000 ohm), sensitive galvanometer, thermometer, thermocouple, 2 beakers, metre bridge, ordinary galvanometer, connection wires, a resistance of 10000 ohm shunted by plug key.

Procedure: First find the resistance R of the potentiometer wire using the resistance box, meter bridge and ordinary galvanometer. Do not forget to use the 10 kΩ resistance in series with the galvanometer for rough adjustment of null point.

Next, connect the potentiometer wire in series with the resistance box R_1, key K and storage cell E (Fig 2.50). Make a suitable resistance R_1 in the resistance box so that the potential difference across the potentiometer wire is about 2 mV Calculate this p.d..

P.d. across potentiometer wire = $ER/(R + R_1)$.

By the use of this arrangement, the potentiometer performs the interesting task of providing a very small continuously variable potential difference, with which the small thermo e.m.f. generated is compared.

Now take iced water in one beaker and boiling water in the second. Make the thermocouple by joining copper wire (connection wires) at the ends of the iron wire. Immerse one junction in cold water and the other in hot water. Suspend the thermometer in hot water. Connect the positive lead of the thermocouple to positve end of A of the potentiometer. Connect the other lead to sliding contact J, through the sensitive galvanometer.

Adjust the position of the sliding contact (jockey) on the potentiometer wire so that the galvanometer deflection is zero During this procedure, keep sufficient ice floating in the cold bath so that the temperature of cold junction of thermocouple is maintained at 0°C while that of the hot junction is slowly coming down. When zero deflection in galvanometer is obtained, note the temperature t, of the hot junction and the balancing length l of the potentiometer wire. Record these observations for different temperatures of the hot junction, as it cools by about 10°C each time. Let the current in the potentiometer wire pass continuously during this procedure. It will neither heat up the potentiometer wire significantly, nor cause a significantly droping the e.m.f. of storage cell

due to discharging, because it is a very small current (or the order of 0.5mA).

For each temperature of hot junction, calculate the thermo-e m.f. generated, *e*:

$$e = ERl/L(R+R_l)$$

where l = balancing length of potentiometer wire, and

L = total length of potentiometer wire.

Plot a graph between *e* and *t* (Fig. 2.51). Find the slope of the graph *e*/*t*.

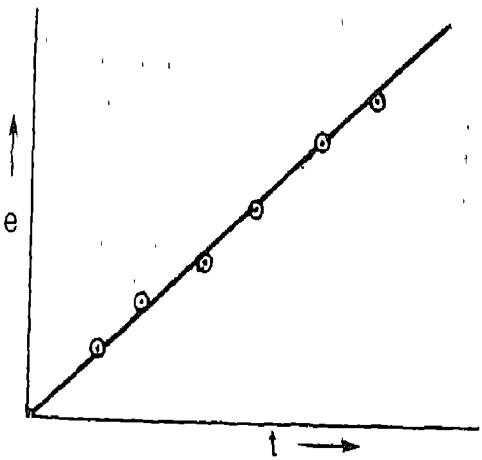


Fig. 2 51 *Graph showing thermo-emf as a function of temperature difference between the two junctions.*

Notes 1 To perform this experiment you require a sensitive galvanometer with taut suspension movement as in demonstration experiment 2.18. You also require some skill in using it. Thus, if you have both and you are interested in doing this experiment, then it may be taken up as a project work.

2. If you are doing this experiment as a project work, use various thermocouples that can be made by three or four materials. Find in each case the increase in thermo-e.m.f. per degree celsius rise in temperature of hot junction (*e*/*t*) Are these results for various thermocouples related in some way? Does the slope of graph *e*/*t* for a thermocouple depend on the temperature of the hot junction?

3. A good alternative to using potentiometer for measuring thermo-e.m.f at various temperatures, is to use a sensitive galvanometer as a micro-voltmeter, as was done in the demonstration experiment 2.19. The apparatus required and procedure is, then, identical to experiment 2.19. Heating arrangement of the above experiment 2 30 may be used (in place of the sand bath of experiment 2.19) for better accuracy in measuring temperature of hot junction by a mercury thermometer. However, a small error in measuring temperature arises on account of Peltier effect coming into play when current passing through the two junctions is not zero. It makes the experiment simpler to do, but you still need a sensitive galvanometer with taut suspension movement and skill of using it. A few bright students can take it up as a laboratory experiment, followed by another one to use this thermocouple thermometer for finding the melting point of wax.

THEME III

Magnetism and Electromagnetism

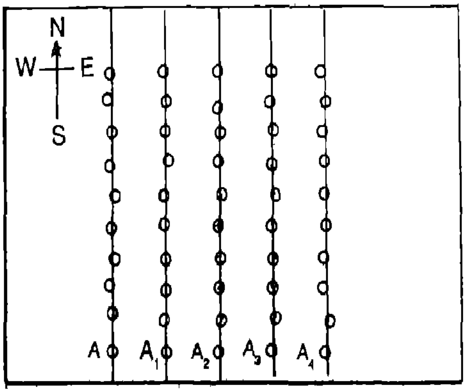
WE have seen that moving electric charge constitutes an electric current. We also studied the thermal and chemical effects of electric current. In this theme, we shall study through experiments, yet another effect of the moving charges, namely the magnetic effect.

TOPIC I MAGNETIC FIELD OF A PERMANENT MAGNET

3.1 (Activity): Use of compass needle as a probe.

Take a compass needle. Place it on a sheet of paper placed on the table. Observe that the needle points in a definite direction, which is approximately the north-south direction. Record this direction by marking a point in front of each pole of the compass and joining them. Displace the position of needle on the table and again note the direction of the needle. You will notice that wherever you place it and how-so-ever you rotate it (keeping it horizontal), it always comes to rest in a definite direction. Doesn't it surprise you?[1] Compass needle serves as a good probe to investigate the magnetic field at a place, in much the same way as an electric charge serves as a probe to detect an electric field. The direction of magnetic field at that place is indicated by a line drawn from its south pole to its north pole.

Mark any point A near the south edge of the paper (Fig. 3. 1a). Place the compass such that its south pole coincides with this point and mark a point B in front of the north pole. Then shift the compass to a position such that B coincides with south pole of the compass and mark a third point C in front of new position of north pole.



(a)

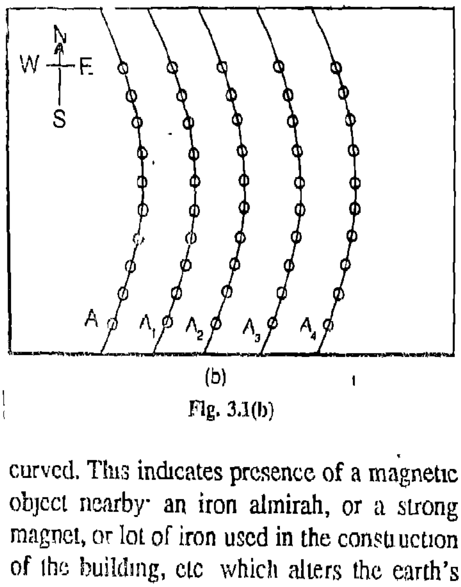
Fig. 3.1 *Magnetic Field pattern in your laboratory (a) due to earth alone (b) in the vicinity of a magnetic material*

[1] At the age of 5 years, Albert Einstein was given by his father, a compass needle as a toy. While playing with it, he was surprised by the determined behaviour of the compass needle to come to rest in a definite direction. The impression of this determined behaviour lasted with Einstein till the end of his life and prompted him to take to science.

Continue like this, step by step, till you reach the north edge of the paper. Join all points by a smooth curve. You get a line of force, because the tangent to this line at any point, indicates the direction of the magnetic field at that point.

Starting from a few more points A_1, A_2, A_3.... near the south edge of paper draw a few lines of force. You get a pattern as shown in Fig. 3.1a. This is the field pattern of earth's magnetic field on your table. You will see that the earth's magnetic field at all the points is in the same direction. This is indicated by parallel lines of force. Besides being in the same direction, the strength of this field is also the same at all points.

You may, get a pattern in your experiment, as shown in Fig. 3.1b., the lines of force being



(b)

Fig. 3.1(b)

curved. This indicates presence of a magnetic object nearby: an iron almirah, or a strong magnet, or lot of iron used in the construction of the building, etc which alters the earth's magnetic field.

3.2 (Experiment): To map the magnetic field due to a bar magnet with north pole of the magnet pointing towards north in the presence of earth's magnetic field.

Apparatus : A bar magnet, a plotting compass (a small compass of between 12 mm to 20 mm diameter), a half metre scale, a sharp pencil, drawing board, sheet of paper, an accurate compass of above 50 mm diameter.

Procedure . We can never map the field lines of a bar magnet alone. The magnetic field of the earth is invariably super-imposed over the field of the magnet. At every point, therefore, what we get is the resultant field which is the vector sum of the two fields A compass needle in such circumstances would point in the direction of the resultant field. At certain points, the compass needle may not show any preferred direction. These points are called neutral points. At these points, horizontal component of earth's magnetic field is equal and opposite to the field due to the magnet. One may plot the combined field of earth and magnet keeping the magnet in any position of one's choice. In this experiment, you will keep the magnet with its N-pole towards north.

Fix a paper on the drawing board. Draw a line joining mid-points N and S of the longer sides of the paper (Fig 3 2). In order to orient

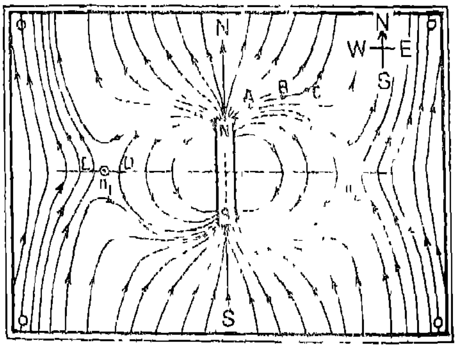


Fig. 3 2

this line along the direction of earth's magnetic field, put the large compass at the middle of this line. (Put all magnets and magnetic substances away from the drawing board). Rotate

the board till the middle line NS is parallel to the compass needle. During this process, tap the board gently to ensure that friction between the needle and its pivot is minimised and that it rotates freely. In such a case the needle will point along the north-south direction.

Place the magnet symmetrically in the middle of line NS as shown in the figure with its north pole pointing towards north. Mark the boundary of the magnet with a sharp pencil. This will enable you to place the magnet in the same position, just in case it is accidentally disturbed during the experiment.

Place the plotting compass near the north pole of the magnet. Tap it gently and mark two dots A and B against the two pointed ends of the compass needle with the tip of a sharp pencil. Then shift the compass so that south pole of the needle coincides with the second dot B (the one against the north pole of the compass needle in previous position) and mark a third dot C now against the north pole of the compass needle. In this manner, go on step by step till the other end of the magnet is reached. A smooth free-hand curve drawn through the points marked on the paper gives a magnetic line of force.

Plot several lines of force around the magnet, indicating their directions by arrow-heads. You will notice an area around the point n_1 (Fig. 3.2) such that the fields at D and E are in opposite directions. Thus going from D to E the direction of the field reverses. This region is the neutral point region. There is another similar region around the point n_2.

Lines of force should be plotted with care in the vicinity of neutral points. To locate the neutral points accurately, plot the lines in this region as close to each other as possible. Lines plotted in this region need not be plotted from the poles of the magnet and may be rather short in length, i.e., you may plot only small portions of lines of force in order to narrow down the neutral point regions.

In a neutral point region, place the plotting compass at such a position by trial and error that its needle stays in any direction and has no preferred direction. Mark the circular boundary of the compass. The centre of this circular boundary gives the position of the neutral point. In this manner locate both the neutral points n_1 and n_2.

Notes 1. It may be noted that a line of force is a smooth curve, whereas in obtaining a few points on a line of force we, inevitably, move in small steps slightly larger than the diameter of the plotting compass. Figure 3.3 explains

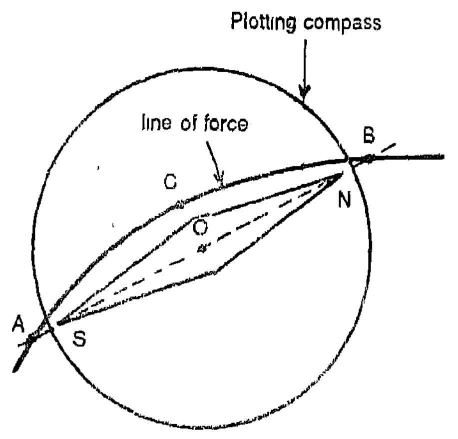


Fig. 3.3

how we obtain points on a line of force with minimum error. Suppose ACB is an actual line of force passing through the point A, which is arbitrarily chosen as the starting point. NOS is the magnetic axis of the compass needle. We adjust the location of compass such that A lies on the line NOS. Then mark the point B on this line against the pole N. The line AB is in fact a tangent to the line of force (curve) which passes through the centre of AB. Smaller the compass needle more accurately it will repro-

duce the curve. On the other hand there is inevitably some experimental error in marking the points A and B. Thus angle between line AB as marked by you and correct direction of compass needle is larger, the smaller is the compass needle. A compass of diameter between 12 mm and 20 mm represents the best compromise, for plotting the magnetic field of common laboratory magnets on a drawing board of about 38 cm x 45 cm.

2. Sometimes, a more expensive kind of plotting compass is used, in which the magnetic needle is supported between two glass sheets. The magnetic needle is arrow-shaped (Fig. 3.4).

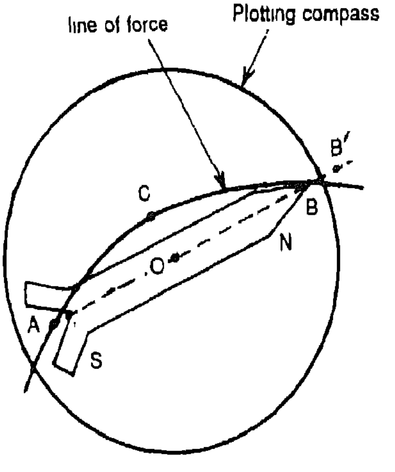


Fig. 3 4

Experience shows that it does not give a good field pattern. In an effort to increase accuracy, while plotting the lines of force, its position is so adjusted that the previous point A comes in the cavity at the south pole of the magnetic needle. Then the point B is marked against the north pole outside the compass It is not possible to mark the point B just at the north pole of needle, through the glass. Main reason for usual failure of this kind of compass is, however, technical. Unless it has jewelled bearings at both ends of the axle of the needle, friction in this type of compass is significantly more than that in which the magnetic needle is suspended on a sharp pin.

3.3 (Experiment): To map the magnetic field of a bar magnet with north pole of the magnet pointing towards south, in the presence of earth's magnetic field.

Apparatus . Same as in experiment 3.2

Procedure · Same as in experiment 3 2, except that the line in the middle of the paper joins the mid-points N and S of the shorter sides of the paper (Fig 3.5) and this line is adjusted to be

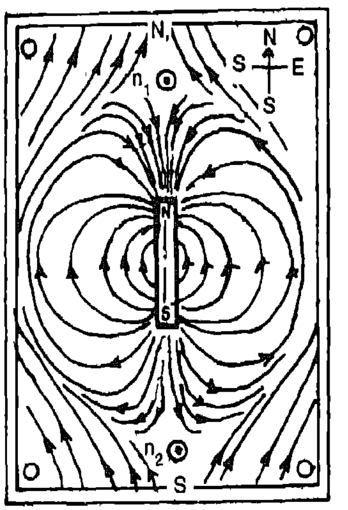


Fig. 3.5

along the magnetic meridian. This enables maximum available space for locating the neutral points n_1 and n_2, which lie on the north and south of the magnet.

Exercise: 1. Map the magnetic field of a bar magnet with north pole of the magnet pointing east in the presence of earth's magnetic field.

2. Map the magnetic field of a bar magnet with north pole of the magnet pointing to west in the presence of earth's magnetic field.

Apparatus and procedure for both these exercises is the same as that in experiment 3.2. With north pole of magnet pointing towards east (exercise 1), two neutral points may be expected, one in the north-west and other in south-east of the magnet. In exercise 2, one neutral point may be expected in the north-east and the other in the south-west of the magnet.

3.4 (Demonstration): To demonstrate the lines of force of a magnetic field with the help of iron filings.

Take a strong bar magnet of length 7.5 cm or 10 cm. Place it in the centre of and under a glass sheet of 30 cm x 30 cm size. Sprinkle fine dry iron filling around it on the glass sheet. Keep the glass sheet horizontal by supporting the four corners on four wooden blocks, and check it by a spirit level. Now gently tap the glass sheet several times. The iron filings arrange themselves in a regular pattern as shown in figure 3.6. This happens because under the influence

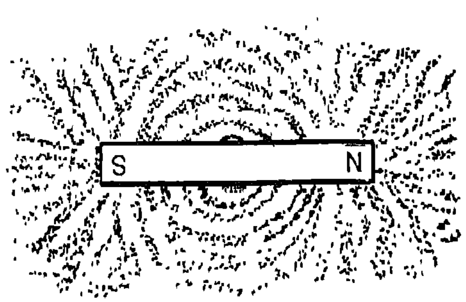


Fig. 3.6 *Iron filings near a bar magnet align themselves along the lines of force.*

of magnetic field, iron particles behave like small magnets and form long chains along the lines of force of the magnetic field. It may be noted that these chains start from the north pole of the magnet, end at the south pole and avoid contact with middle portion.

The pattern of iron filings on glass sheet may be fixed by spraying clear lacquer paint on the glass sheet. After it becomes dry, it can be put up as a permanent display.

An alternative way to make a permanent record of pattern is to stick a 30 cm x 30 cm sheet of ferrotype paper on the glass sheet with adhesive tape along the four edges. The paper must become almost as plane as the glass sheet without any wrinkles in it. The entire experiment is, then, done on this ferrotype paper. After the pattern is formed, the glass sheet (along with the paper and iron filings on it) is put in the sun undisturbed. After developing this ferrotype paper, a shadow photograph of the pattern is obtained. For best results, the sun-light should fall on the glass sheet nearly perpendicular to its surface.

Questions : 1. Suppose you perform the experiment with a plotting compass as follows You place the magnet below a thin glass plate (or a plane sheet of thin plywood or thick cardboard). Fix a paper on the plate and adjust it horizontal with a spirit level. Then you plot the lines of force with a plotting compass. What kind of lines of force do you expect to get? Does any line of force make a complete loop through the magnet?

2. Why iron particles align themselves in the pattern of lines of force in the experiment 3 4 above? (Each iron particle becomes a tiny magnet in the vicinity of a powerful magnet).

3. Observe a pattern of lines of force and try to infer the relation between gap between two adjacent lines of force and strength of magnetic field in this gap, and state what inference do you draw from it. (Smaller the gap, stronger is the magnetic field).

3.5 (Demonstration): To demonstrate the lines of force of a magnet in three dimensions.

Place a strong bar magnet (length 10 cm) on

a drawing paper fixed on a horizontal drawing board with its north pole towards north. Plot a few lines of force of this magnet, as in experiment 3.2, on one side of the magnet, say to east of the magnet, with the help of a plotting compass.

Now take a tracing paper, half the size of the drawing paper. Keeping its longer edge coincident with axis of the magnet, copy the lines of force on the tracing paper. Next, fix the tracing paper on a cardboard so that its edge coincides with an edge of the cardboard. Fix the cardboard in an inclined plane, with its edge coinciding with the axis of the magnet (Fig. 3.7). The lines drawn on tracing paper now represent the lines of force of the magnet in the plane of the cardboard, which is not a horizontal plane. Bring the centre of a small dip needle (a magnetic needle capable of rotating in a vertical plane) at any point on a line of force on the cardboard and make its plane of rotation parallel to the cardboard Observe that the dip needle aligns itself tangential to that line of force.

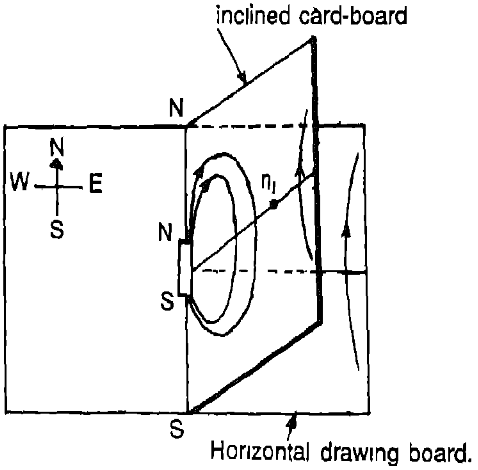
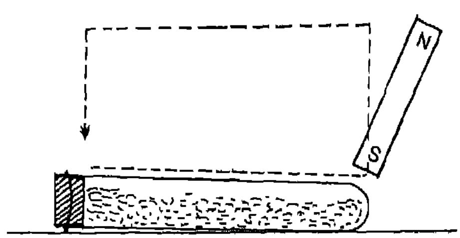


Fig. 3.7

You can easily construct a 3-dimensional model of the lines of force. You need some copper or aluminium wires of 16 SWG. Corresponding to each line of force drawn on the horizontal drawing board, make 6 or 8 pieces of wire which are so bent as to coincide with that line from north pole to south pole of the magnet. Make a wooden strip of square cross-section equal in length to the magnet. At each end of wooden strip drill a hole of 6 mm diameter and about 10 mm deep. Support the wires (representing lines of force) in the two holes in various planes around the wooden strip. It can be put up as a display by hanging the wooden strip horizontal with the help of two threads tied near its ends. In this display the wires have to be held firmly as they tend to hang down.

3.6 (Demonstration): To demonstrate that an aggregate of iron filings when suitably magnetised behaves as a magnet.

Take a test tube Fill it about 5/6th with iron filings. Close the tube with a rubber or cork stopper. Attempt to plot the lines of force due to this aggregate of iron filings. You will see that except in the close vicinity of the test tube, the compass needle essentially plots the earth's magnetic field. Now stroke the test tube repeatedly with the help of a strong bar magnet as shown in Figure 3.8a Now plot the lines of



(a)

Fig. 3.8(a)

force. You will notice that the map of lines of force is similar to the one produced by a bar magnet. You will thus see that by aligning the iron dust along a particular direction, the whole aggregate shows a cooperative phenomenon. Previous to magnetisation, these tiny magnets in the form of iron filings were oriented in random direction, so that the net magnetic effect was negligable.

Now shake the tube so that the iron particles change their orientations. You find that the test tube does not behave as a magnet now; any end of the tube weakly attracts either poles of the compass.

Notes: 1. It can be understood easily by this demostration that the common bar-magnet is essentially a collection of tiny magnets all aligned in a particular direction. By mechanical rough handling or by heating, the alignment of these tiny magnets tends to get disturbed and the magnet becomes weak. Finally at a certain temperature, it ceases to show its magnetization characteristics.

2. The atomic/molecular magnets inside a magnet are aligned along the lines of force passing through the magnet.

3. When we refer to, say, north pole of a bar magnet, we do not talk of a precise point. It is only a loose reference to entire surface at one end where north poles of molecular magnets are distributed (Fig. 3.8b). The magnetic axis of a bar magnet is, however, a precise line It is a line about which the lines of force are symmetrical (in 3-dimensions)

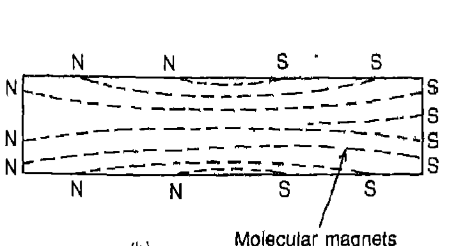


Fig. 3.8(b)

TOPIC II: MAGNETIC FIELD DUE TO A CURRENT CARRYING CONDUCTOR

3.7 (Demonstration): To show that a conductor carrying an electric current produces a magnetic field in the surrounding space.

Connect one end of 16 SWG copper wire to one terminal of a storage battery and the other to a tapping key K through a rheostat R. Place a compass needle on the table and adjust the wire parallel to and a few centimetres above the needle. Complete the circuit by a piece of 16 SWG copper wire (Fig. 3.9a) Momentarily, press the key. As soon as the current flows through the wire, the needle swings. Note the direction in which current carrying wire deflects the north pole of the compass needle This direction, which is perpendicular to the direction of the earth's magnetic field (magnetic meridian), is the direction of the magnetic field produced by the electric current at the north pole of the needle.

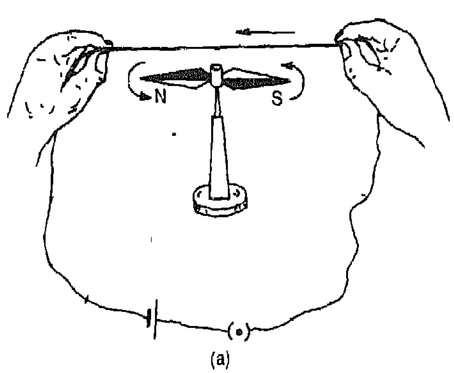


Fig. 3.9 *A straight conductor carrying current deflects a magnetic needle showing that it has a magnetic field.*

Repeat the experiment keeping the wire below the needle and note that north pole of magnetic needle is deflected in the opposite direction (Fig. 3.9b). Clearly the magnetic field

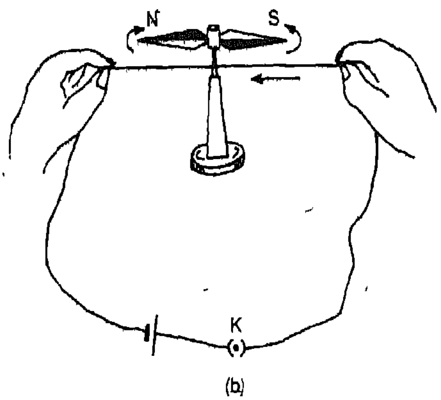


Fig. 3.9(b)

of the current carrying wire is such that lines of force encircle the wire. Check from these two observations that the magnetic field is in accordance with the right hand rule illustrated in Figure 3.10.

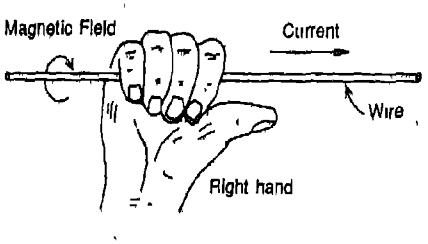


Fig. 3.10 *The right hand rule.*

3.8 (Experiment): To sketch the lines of force of a straight long vertical conductor carrying current and earth together.

Apparatus: The apparatus consists of a copper wire AB (SWG 18 or 16) bent into a square of side one metre supported in a vertical plane through two holes in the table (Fig. 3.11a).

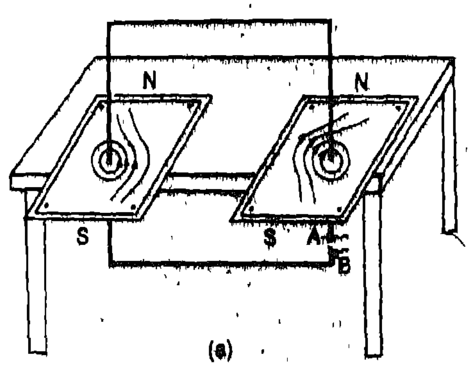


Fig. 3.11 *Mapping the magnetic field due to a straight conductor carrying current, (a) the square coil for it and (b) the electrical circuit.*

A dc supply (6A, 6V to 12V)[1], a rheostat (6A, 10 ohm), ammeter (0-10A) and a plug key, a plotting compass, an accurate compass of 50 mm diameter.

Procedure : Connect the wire in series with dc Power supply, plug key, rheostat and ammeter (Fig. 3.11b).

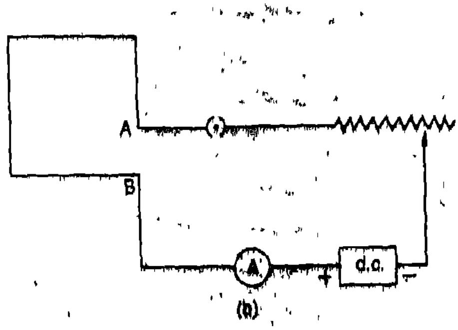


Fig. 3.11(b)

[1] If a square coil as described in appendix 5 is used, a small battery of 2 dry cells is good enough for this experiment.

All wires carrying current should be kept atleast two metre away from the square loop. One square loop has two vertical arms and can, thus, serve for two students working on this experiment.

Take a graph paper (about 20 cm x 25 cm). Make a hole in the centre, and a cut from the hole to one of the sides of the paper as shown in Figure 3.12. Making use of this cut, insert it

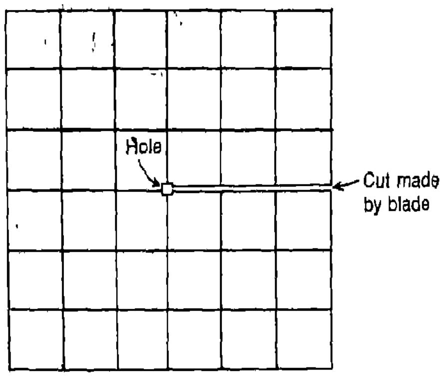


Fig. 3.12

such that the vertical side of the wire passes through the hole and fix it on the board as shown in Fig. 3.11a. Adjust its orientation in such a way that a set of parallel lines on the graph paper corresponds to the horizontal component of the earth's magnetic field. In the absence of current through the square loop of the conductor, the compass needle will plot the earth's magnetic field. Now pass a steady current of say 5A through the conductor. Now you will see that the orientation of the compass needle depends upon the place where it is kept. This means that when electric current is passed through the conductor, it produces a magnetic field. Plot the resultant of the magnetic field produced by current carrying conductor and the earth's magnetic field. You will see that close to the vertical straight edge of the conductor, the lines of force are concentic circles with no beginning and no end. In the map of the lines of force you will see the existence of a neutral point A. (There is only one in this case, in contrast to two in case of the field of a magnet). Plot more lines in this region and locate the neutral point as accurately as possible The current should remain steady during the experiment.

Measure the distance, d, of neutral point from the centre of the hole (Fig. 3.13) Calculate the

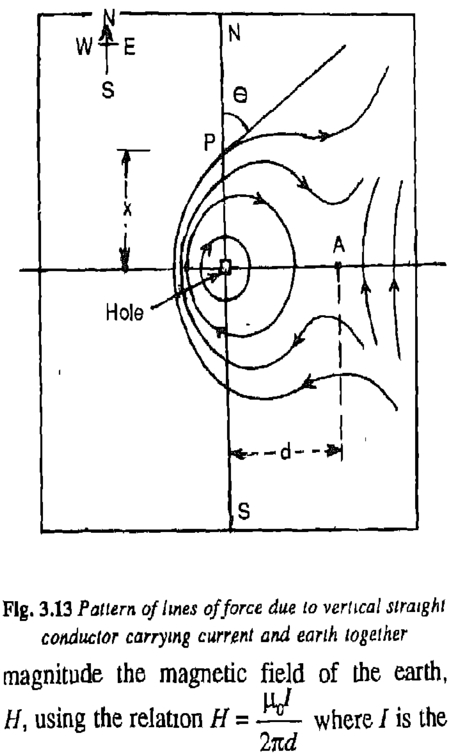


Fig. 3.13 *Pattern of lines of force due to vertical straight conductor carrying current and earth together*

magnitude the magnetic field of the earth, H, using the relation $H = \frac{\mu_0 I}{2\pi d}$ where I is the current passing through the wire and μ_0 is the permeability of air $\approx 4\pi \times 10^{-7}$ Tm/A

Through the centre of the hole, draw a line NS, in the direction of horizontal component of earth's magnetic field, (Fig. 3 13) It cuts a typical line of force at point P at a distance x from the centre of the hole. Draw a tangent to this line of force at P Let it make an angle θ

with the line NS Then magnetic field due to the current at point P is:

$$B = H \tan \theta$$

At each point where line NS cuts a line of force, measure x and θ and calculate B in terms of H. Plot a graph between B and $1/x$. If you get a straight line passing through the origin, it shows that B is inversely proportional to distance x

3.9 (Activity): To show that a solenoid carrying an electric current produces a magnetic field similar to that produced by a bar magnet.

Take a solenoid of thick enamelled copper wire (16 SWG) mounted on a horizontal board (Fig. 3.14a). Its loops are large enough to manipulate a small compass inside it[3]. Recommended dimensions are diameter 6 cm, length 15 cm fitted in the wooden board 28 cm x 38 cm. Take a drawing paper of the same size as the board, cut two slits in it as shown in (Fig. 3.14b) to accommodate the solenoid, draw the axis of

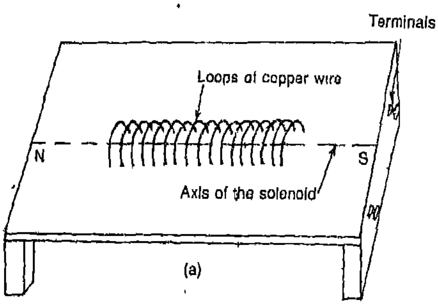


Fig. 3.14(a)

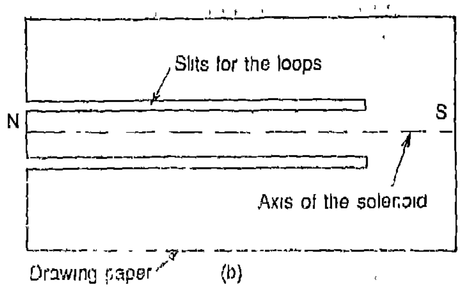


Fig. 3.14(b)

solenoid on it and then fix it on the board. Place a large accurate compass (diametre 50 mm) on the line representing axis of the solenoid and adjust orientation of the board so that this line is in the north-south direction, i.e. parallel to the compass.

Connect the solenoid in series with a rheostat R, key K, lead acid battery B and ammeter A (Fig. 3.14c). Switch on the current and

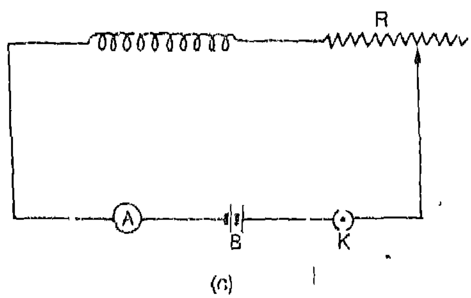


Fig. 3.14(c)

adjust rheostat so that a current of 0.1A to 0.3A passes through the solenoid. Place the plotting compass inside the solenoid and check that when current is switched on, the compass needle reverses its direction, indicating that magnetic field of the solenoid is stronger than and opposite to that of the earth. For this pur-

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[3] Full details as to how to construct such a solenoid are explained in appendix 7.

pose you may have to adjust the direction and magnitude of current. Place the plotting compass at the extreme ends N and S of the axis of the solenoid (Fig. 3.14a) and check up that at these points the north pole of compass needle is towards north, indicating that earth's magnetic field is stronger than that of the solenoid. This ensures that two neutral points exists on the drawing paper and not beyond it.

Now plot the lines of force of the combined magnetic field, due to the solenoid and the earth, as explained in experiment 3.2. See that the ammeter reading does not change during the experiment. If you get a pattern similar to that shown in (Fig. 3.5), it shows that the solenoid carrying current behaves as a bar magnet, with its north pole pointing towards south.

The experiment can be repeated with direction of current reversed so that inside the solenoid, its magnetic field is in the same direction on that of the earth. In this case you get neutral points along the east and west of the solenoid. Thus the solenoid behaves as a bar magnet with its north pole pointing towards north.

Note: A noteworthy difference in the field patterns of the solenoid and bar magnet is the following. In case of solenoid, you can place the compass inside the solenoid. Thus you find that lines of force are closed loops. In case of bar magnet the lines of force start from the north pole of the bar magnet and end at the south pole. In fact, the lines of force are closed loops in case of a bar magnet too; they continue inside the bar magnet though we cannot plot them inside the magnet with the help of a compass. The tiny molecular magnets of which the macroscopic bar magnet is composed, are aligned along the lines of force inside the magnet. However, in case of an electrostatic field, lines of force start from positive charges and end on negative charges. This difference is due to the fact that isolated positive and negative charges exist, whereas, isolated north and south poles do not exist.

3.10 (Demonstration): To demonstrate the construction and working of the deflection magnetometer.

It consists of a short bar magnet M (Fig 3.15) called *needle*, pivoted so that it can move freely

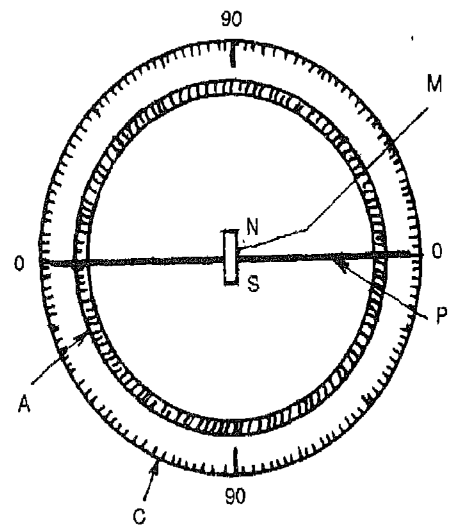


Fig. 3.15 *The deflection magnetometer*

in a horizontal plane. A long, light-weight pointer P made of aluminium is attached perpendicular to the magnet needle M. It moves over a circular scale C marked in degrees. The instrument is fitted with an annular circular mirror A. When deflections of the needle are being observed by the pointer, the eye can be adjusted to be in line with the pointer and its image in the mirror.

When there is no magnetic field other than that of earth, the magnetic needle comes to rest in the magnetic meridian under the action of the horizontal component, H, of earth's magne-

tic field. When a deflecting field of intensity B acts on the needle in addition to the earth's field at right angles to it, the position taken by the needle is along the resultant of the two magnetic fields B and H (Fig. 3.16). The needle

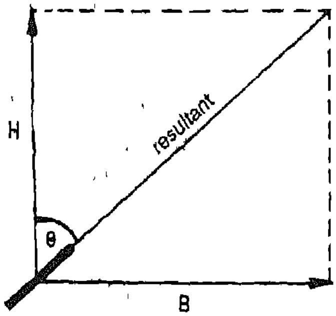


Fig. 3.16 *Magnetic needle of the deflection magnetometer points in the dirrection of the resultant magnetic field Thus it rotates through angle* θ.

thus deflects through an angle θ from its position of rest in the magnetic meridian such that.

$$\tan\theta = \frac{B}{H}$$

Sometimes, the deflection magnetometer is fitted in a frame which consists of two arms, each 50 cm long. They are fitted with scales marked in millimeters, which indicate the distance from the centre of the instrument. Thus, the scale on both the arms have a common zero, at the centre of the instrument (Fig. 3.17). The

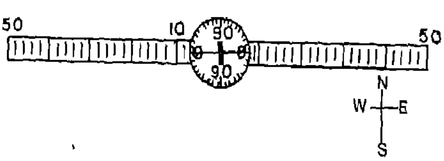


Fig. 3.17 *The deflection magnetometer along with its one meter long frame.*

scales are so fitted that a bar magnet placed on any of them, is in the same horizontal plane as the magnetic needle at the centre of the instrument.

3.11 (Experiment) To study how the magnetic field due to a long straight conductor carrying current varies with
(a) the current in the wire, and
(b) the distance from the wire.

Apparatus. Deflection magnetometer fitted in the centre of 1-metre frame, about 2 1/2 metre of thick copper wire (SWG 16), glass tube of 1 metre length, rheostat (5 A current-capacity) ammeter (0-5A), d.c. supply (6V, 6A), reversing key, spirit level, half-metre scale, two wooden clamps

Procedure . Adjust the circular scale of the deflection magnetometer so that the line joining the 90°-90° marks coincides with the common axis of the two arms. Adjust the whole instrument so that the aluminium pointers (which maintain east-west direction) are at zero-marks. Then the two arms are in the magnetic north-south direction. With the help of spirit level, adjust the plane of the two half metre scales horizontal.

Pass the copper wire, HK, through the glass tube (Fig. 3.18). Copper wire, L,L, near the two

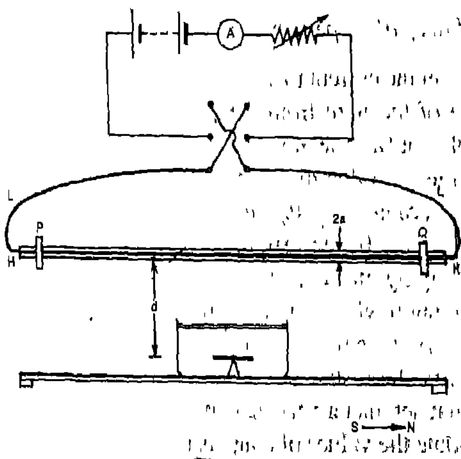


Fig. 3.18

ends act as leads and the length HK is the straight conductor to produce magnetic field B perpendicular to earth's field at the magnetic needle. Connect these leads to reversing key, making a large loop and complete the circuit as shown in Fig. 3.18. With the help of spirit level and clamps P,Q, adjust the glass tube parallel to and about 3 cm above the two arms of the magnetometer.

(a) To Study Dependence of B on I:

Adjust the current to between 2A and 3A. Adjust the distance of the tube, d, from the plane of the magnetic needle, until a deflection of about 45° is obtained. Keeping this distance constant, vary the current to obtain deflections of the magnetometer ranging between 25° and 65°. Read both ends of the pointer (θ_1, θ_2) and again with the current reversed (θ_3, θ_4). Thus find the mean deflection, θ, for each value of current. Tabulate the values of tan θ against corresponding values of current. Plot a graph between tan θ (taken along Y-axis) and current I (taken along X-axis). If the graph is a straight line passing through the origin, it infers that the magnetic field due to the current is directly proportional to the current in the wire.

(b) Study of Dependence of B on d:

Next set the current to about 5A. Adjust the distance of the wire from the plane of magnetic needle, until a deflection of about 45° is obtained and measure this distance, d. Read both ends of the pointer (θ_1, θ_2) and again with curent reversed(θ_3, θ_4) and find the mean deflection, θ. Keeping the current constant, except for reversing it when required, and using the spirit level to ensure that the wire is always horizontal, vary the distance d to obtain deflection in the magnetometer varying between 25° and 65°. Tabulate the values of d against corresponding values of tan θ. Because distance of axis of wire from magnetic needle is $d+a$, where a is the radius of the glass tube, tabulates values of $1/(d+a)$ as well. Plot a graph between tan θ and $1/(d+a)$. If the graph is a straight line through the origin, it infers that the magnetic field due to the current is inversely proportional to its distance from the magnetic needle.

3.12 (Demonstration): To demonstration that a coil carrying current acts as a magnet and keeps its axis in north-south direction in the earth's magnetic field.

Take the circular coil of radius 4 cm and of 600 turns[4]. Connect it to two 3 volt batteries in series, each consisting of 2 dry cells. Include a bed-switch in the circuit to switch on and off the current in the circuit. Put the whole equipment in a small plastic trough (inside diameter 30 cm). Put the two batteries, one on each side of the coil, and adjust their positions such that the trough floats horizontally on the surface of the water filled in a larger trough.

Now switch on the current and observe that the axis of the coil oscillates in a horizontal plane about the north-south direction, just as a suspended magnet does. After a few oscillations it comes to rest in the north-south direction. You will thus see that the circular coil carrying current behaves as a compass needle.

Note : An alternate way of showing this demonstration is to take a coil of about 500 turns and outer diameter 41 mm made over a dry cell of length 60 mm and outer diameter 33 mm[5]. When ends of the coil are joined to the cell terminals and a current passes in the coil, it behaves as a magnet. Place the coil on

[4]Details of construction of this coil are given in appendix 6.

[5]Details of construction of this coil are given in appendix 8.

a wire frame hanging by an unspun silk/nylon thread (i.e vibration magnetometer as shown in Fig 3.33). When no current is passing through the coil, it sets in any direction However, on passing the current, it sets with its axis in the north-south direction. Indeed with such a contrivance, we can plot the lines of force due to magnetic field produced by a bar magnet, current carrying conductor, etc. provided the spatial span of that magnetic field is much bigger than size of the coil, just as the spatial span of the magnetic field you plotted on the drawing board was much bigger than size of the plotting compass in experiment 3.2.

3.13 (Demonstration): To demonstrate that the motion of a moving charge is influenced by a magnetic field.

Take a cathode-ray tube in which the anode has a small horizontal slit. A narrow beam of electrons passes through the anode and makes a trace EF at grazing incidence on the vertical fluorescent screen ABCD (Fig. 3.19a).

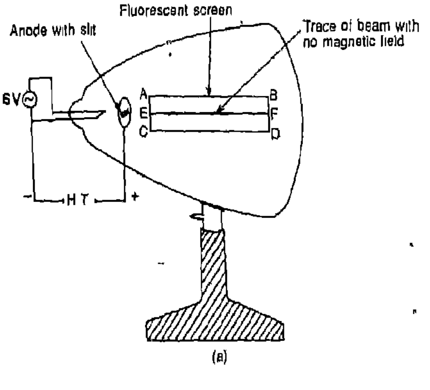


Fig. 3.19

Bring a strong bar magnet near the cathode-ray tube, keeping it perpendicular to the screen (i.e. its magnetic axis horizontal) with its north pole pointing towards the screen (Fig. 3.19b). The electron beam is seen to bend downwards, if electrons are moving horizontally towards the right. Next, keep the south pole of the magnet pointing towards the screen. In this case the electron beam is seen to bend upwards.

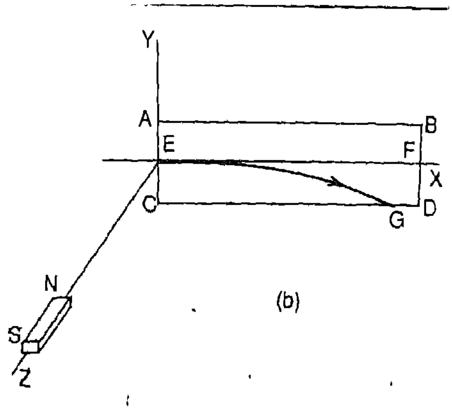


Fig. 3.19(b)

This experiment shows that electron beam moving to right behaves as conventional current flowing towards left, which experiences a force in the magnetic field of the magnet, according to Fleming's left hand rule (Fig. 3.20).

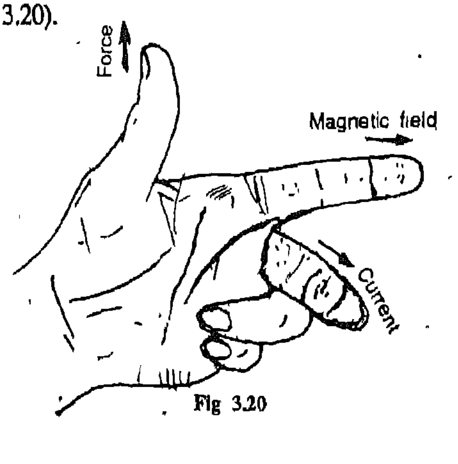


Fig 3.20

Note : If this special equipment is not available, you can demonstrate the same effect with a simple cathode-ray-oscilloscope. In this case the anode has a small hole P. A narrow beam of electrons passing through it strikes the fluorescent screen S. Bring the magnet NS near it and observe the deflection of the bright spot R (Fig. 3.21).

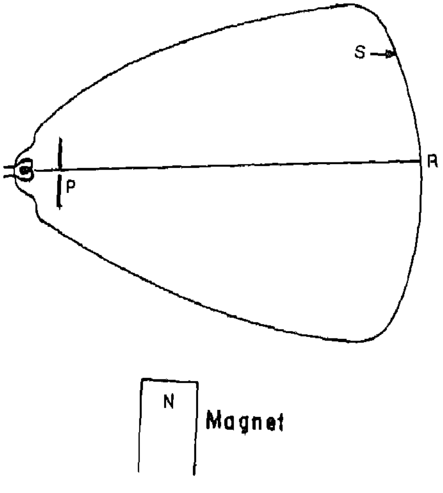


Fig. 3.21

3.14 (Demonstration): To demonstrate that the strength of the magnetic field due to a coil is affected by the material of the core round which it is wound.

Take the solenoid of experiment 3.9 shown in Fig. 3.14a. Place a deflection magnetometer (only circular box with magnetic needle) on a wooden block so that its magnetic needle is in the same horizontal plane as the axis of the solenoid. Place the solenoid to the east or west of the magnetic needle so that centre of the magnetometer lies on the axis of the solenoid (Fig. 3.22).

Connect the solenoid in series with a rheostat R, key K, battery B and ammeter A (Fig. 3.10c). Switch on the current and adjust rheostat so that its magnetic field deflects the magnetic needle of magnetometer through about 25°. Now, insert straight pieces of thick soft iron wire (SWG 10, commonly used in houses for drying clothes), each about 20cm long, into the solenoid. As you add these pieces the deflection of the magnetomer needle increases. Fill the solenoid with iron wire pieces and note that the field produced by the solenoid increases many times over (Remember, field is proportional to $\tan\theta$ and NOT proportional to θ)

Notes . 1. As you insert iron wires in the solenoid, the iron wires get magnetised due to magnetic field of the solenoid. Now the magnetic field of the solenoid as also of the magnetised iron wires deflects the compass needle.

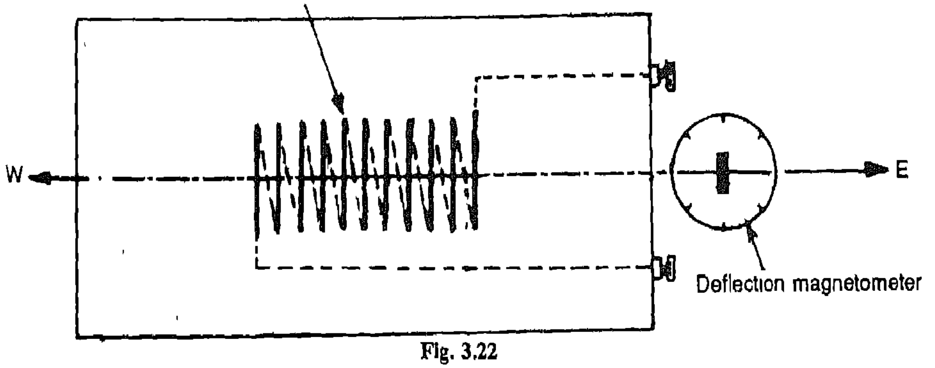


Fig. 3.22

[illegible] the magnetic field and [illegible] along the axis of the solenoid but also in the entire space around the solenoid

2. Instead of iron wires introduce glass rods or wooden rods in the solenoid and observe what happens.

3.15 (Activity) : To study the interaction between two bar magnets

Hang a stirrup of copper wire in a stand by unspun silk/nylon thread Let the thread by which it hangs unwind its twists, if any. Then suspend two bar-magnets in turn on the stirrup. Thus find for each magnet, which end is the north pole and which end is the south pole and mark them on the magnets

Now, keeping one magnet in the stirrup and other in your hand, bring either south poles of the two magnets close to each other or the north poles (Fig 3 23a). Observe that magnet in the hand repels the suspended magnet. This is a mutual interaction. It is thus seen that similar poles of the two magnets (N-N or S-S) repel each other.

Next, bring south pole of magnet in your hand near north pole of suspended magnet and observe an attraction. Bring north pole of magnet in your hand near south pole of suspended magnet and again observe an attraction (Fig 3.23b). It is seen that unlike poles (N-S or S-N) attract each other.

Next, take an unmagnetised iron rod in hand. Bring any end of the rod near any end of the suspended magnet and observe that there is attraction In all the four cases (Fig 3 23c). Since a pole of the suspended magnet attracts opposite pole of the other magnet as well the unmagnetised rod, inference is that repulsion is the sure test of magnetism, if any, in the iron rod held in your hand.

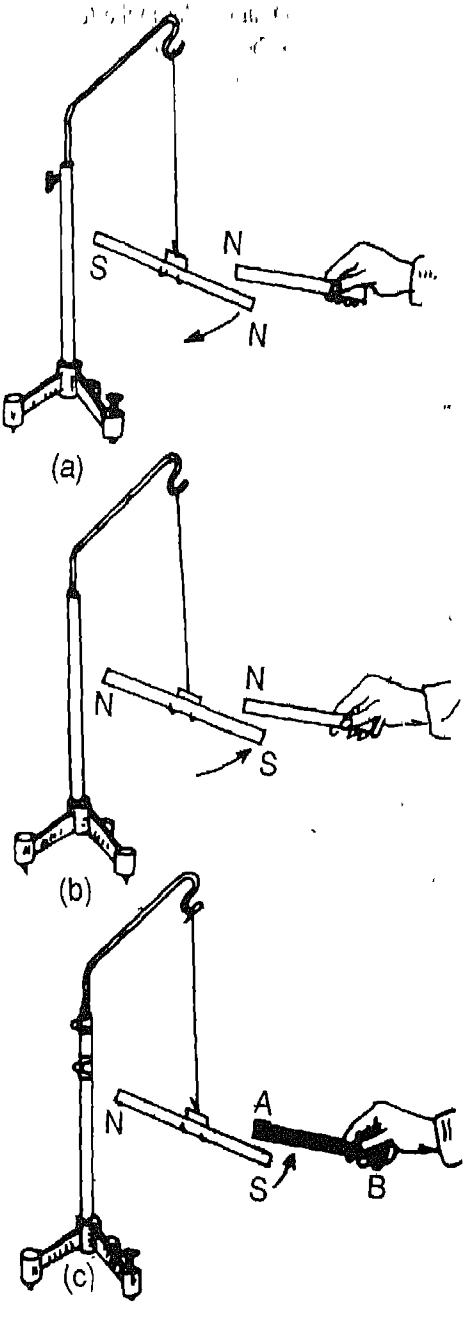


Fig. 3.23 *Repulsion is the sure test of manetism*

Exercise: Take two identical flate ferrite magnets AB and CD and a glass tube (or cylinder or wide mouth bottle with flat base) in which the two can be inserted loose fit. First insert the magnet AB and let it rest at the bottom. Then insert CD and record what you observe. In some situations, the magnet CD seems to float at a certain distance from the magnet AB (Fig. 3.24) Explain your observation. Record which faces of the two magnets face each other when the magnet CD floats.

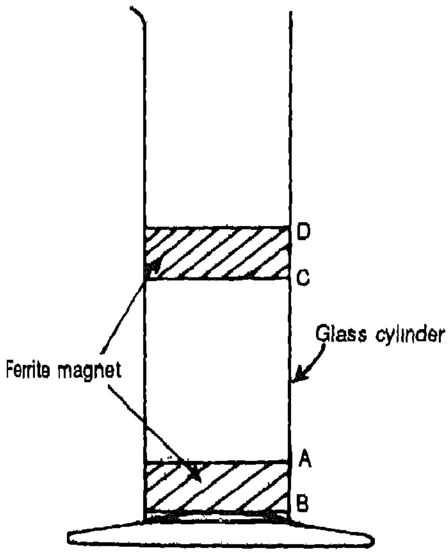


Fig. 3.24 Which faces of the two ferrite magnets are facing each other.

3.16 (Activity) : To study the effect produced on magnetic field pattern, by bringing various materials in the surrounding space of a bar magnet.

Take a strong bar magnet. Place it on a drawing paper fixed on a drawing board so that axis of the magnet is along the north-south direction and its north pole points towards north. With the help of a plotting compass, map its lines of force (in the presence of earth's magnetic field), as you did in experiment 3.2. You get a pattern similar to that shown in Figure 3.2.

Now replace the drawing paper, place the magnet in same position and place a bar of soft iron, SI at some distance from the magnet, say on the north of the magnet, as shown in Fig. 3.25.

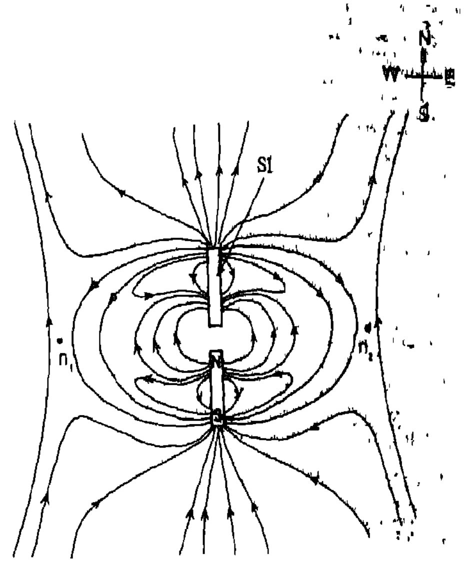


Fig. 3.25 The soft iron bar AB drastically alters the magnetic field pattern.

Again map the magnetic field of the magnet. What the pattern is like now? You observe that it is quite different from the pattern of magnet alone. Many lines of force tend to pass through or close to the soft iron bar, as shown in Figure 3.25. The neutral points also move away from the magnet.

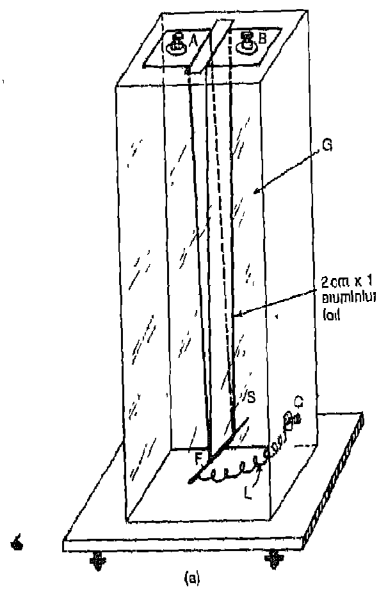
Test the polarity at the ends of the iron bar with the help of a compass. You find that it has become a magnet. The end where many lines of force starting from north pole of the magnet enter the iron bar, behaves as the south pole and the other end behaves as the north pole. Thus the iron bar becomes an induced magnet.

Repeat the experiment with a bar of copper or aluminium or any plastic material. You find that the pattern of lines of force is not altered by the presence of this bar. Also that this bar does not become an induced magnet. With a bar of nickel or cobalt, however, the pattern of lines of force is altered, though not so much as by the soft iron bar.

Materials by which the pattern of lines of force is altered are called ferromagnetic materials.

3.17 (Activity) : To study the interaction between two current carrying conductors.

Take a strip of thin aluminium foil (used for baking articles in the oven) about 1 m long and 2 cm broad. Take a wooden box with glass front, about 60 cm high, 5 cm broad and 5 cm deep. At the top of the box, there is a slit 1 cm broad and 3 cm long (Fig. 3.26a) The two ends of the foil strip are pressed rigidly under terminals A & B at the top of the box. It may be necessary to fold the ends two or three times to secure rigid contact at the terminals A and B. The entire length of the strip hangs inside the box through the slit as shown in Fig. 3.26a. At the centre fold of the strip F, is supported a clean sewing needle whose weight keeps the two halves of the strip taut and straight. The needle also makes an electrical contact with the foil. Through the eye of the needle, a thin bare copper wire L (0.076 mm diameter, taken from a twin flexible electrical cable) is passed and tied. The other end of the coper wire is connected to the terminal C, at the side of the box.



(a)

Fig. 3.26

Level the whole instrument with the help of levelling screws and a spirit level. If one of the two halves of the strip sags, tap the instrument lightly, so that the needle adjusts its position and the sag is removed. It is essential to take care that centre fold F is not made sharp by pressing at it. Let it be only as sharp as the weight of the needle makes it.

Connect this instrument to an accumulator through a rheostat and a double pole double throw switch, as shown in Fig. 3.26b. When the double pole double throw switch joins A to B and C to D, the two halves of the foil FA and FB are in parallel with each other. Starting with maximum resistance in rheostat, slowly decreased the resistance till the current shown by the ammeter is the maximum permissible for the thin wire L, leading to terminal C.[6] In this case, current flows in the same direction in the two halves of the strip. You will see that the two halves of the strip attract. Thus along more than half the vertical length, the two halves of the strip stick together. If the current is switched off, the strip again regains its original V shape.

[6] Find out by an auxiliary experiment, the current by which the thin copper wire fuses. Half of that current may be taken as the maximum permissible current to be passed in it.

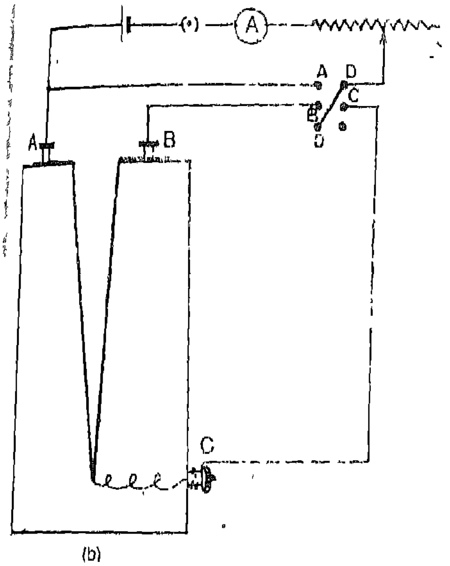


Fig. 3.26 (b)

Next, connect terminals B and D, by the double pole double throw switch. The terminal C is now unconnected. In this case the current flows through the two halves in opposite direction as they are now connected in series. You will find that in this case the two halves of the strip repel each other to acquire U-shape.

3.18 (Demonstration) : To demonstrate the interaction between parallel currents with the help of a jumping spiral.

Wind a helical spring of an enamelled copper wire of SWG 26 or 28. Use a rod of circular crossection and diameter about 3 cm to wind the spring on. Make the spring fairly long (about 100 loops), so that when vertically suspended it elongates substantially under its own weight (Fig. 3.27). In the suspended position, distance between adjacent loops of the spring should be small, about 1 mm to 2 mm.

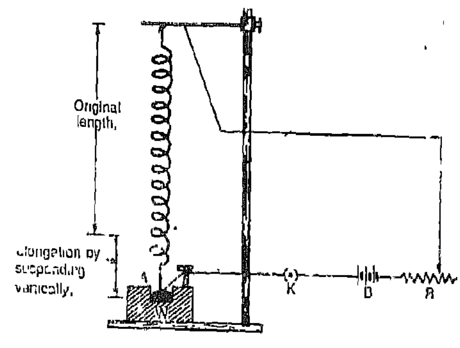


Fig. 3.27 *The jumping spiral.*

Let the lower end A of the spring dip in a drop of mercury kept in a small pit in a wooden block W. Connect the spring in series with a key K, lead acid battery B and rheostat R (0-10 ohm, 6A) as shown in the figure.

On passing a suitable current, the spring starts jumping making and breaking contact with the drop of mercury. This happens because the current in any two adjacent loops of the spring is parallel and in the same direction. Thus adjacenet loops attract each other, thus compressing the spring. As the spring compresses, it breaks contact with mercury. The current ceases to flow and the spring regains its original shape. Then it again makes contact with mercury. The process repeats, giving the appearance of a jumping spiral.

3.19 (Activity) : Construct a simple current balance and demonstrate its working.

A simple current balance is schematically shown in Figure 3.28. A wire frame ABCDEF, of stout bare copper wire (16 SWG) is shaped as shown in the figure. Its free ends A & F are connected to two tapered brass screws passing through a wooden spacing rod R, to pivot in counter-sunk vertical cylinderical brass supports.

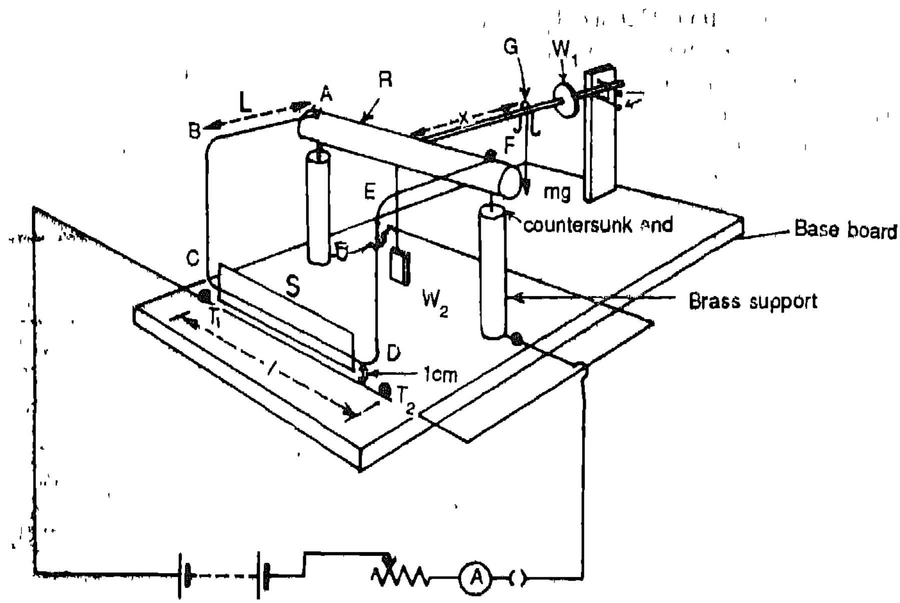


Fig. 3.28 *A simple current balance.*

These supports are firmly attached to a flat wooden base-board with the help of screws inserted from below the base board. A typical suitable dimension for the wire frame is $L = 20$ cm, $L = 20$ cm & height = 10 cm

Attached to the rod R, is a long thin graduated wooden balancing arm G. The free play of its tappered end (a small length at the end of the rod is tapered like a screw driver by rubbing on a fine grain sand paper) is restricted by two stay-pins P in a vertical support. This arm is provided with a counter-poise weight W_1 whose position can be adjusted to make it horizontal when no current is passing in the wire. This arm is graduated with bright marks, say white marks at 2.5 cm spacing and yellow marks between adjacent white marks at 0.5 cm spacing. If finer marking is desired, a thin strips of mm-graph paper may be pasted on it. A rider of mass m, moves along this balancing arm, so that the turning moment of the weight of the rider enables you to measure the downward magnetic force on the horizontal portion CD (of length L) of copper wire.

The whole movable system is stable (i.e. its C.G. is below its axis of rotation) because the portion CD of the wire on which magnetic force acts, is quite low. Still to increase its stability and to control the stability at will, a pendulum like weight W_2 is attached in a thin vertical rod fixed below in the rod R, at its mid-point.

On the base-board, immediately below the portion CD of the pivoted wire frame, an equal length of bare copper wire (16 SWG) is stretched between two terminals T_1 and T_2. The right-hand end of this wire continues as shown in the figure and is connected to a terminal near the left end of the spacing rod R. The left hand end of this wire and terminal near the right hand end of the spacing rod R are connected to an accumulator through a rheostat, ammeter and plug key. The whole assembly is

so arranged that the inter-axial gap between the two horizontal sections CD and T_1 T_2 (which experience force of attraction when current is passed) is uniform i.e. they are parallel to each other. This is checked up by looking at them horizontally against a vertical screen S, made of mm-graph paper, which is fixed on the base-board behind the wires.

The whole assembly is covered by a lid (not shown in the Figure) made of five accrylic sheets (four vertical sides and the top). The top side has a slit through which the rider can be removed and placed at any desired position on the balancing arm G.

First carefully counterpoise the balance with the rider close to the central spacing rod and by adjusting the counterpoise weight W_1, so that tapered end of the balancing arm just rests on the lower stay pin P. Now pass the current by inserting the plug key. Like currents pass along the wires T_1, T_2 and CD, with consequent attraction between them. Re-establish counterpoise (balancing arm pointer again just rests at the lower stay pin) by suitably positioning the rider. Read off the initial and final positions of the rider and thus calculate the distance, x, through which it is moved 'out' on passing the current. Then the force of attraction between the wires is

$$F = \frac{mgx}{L}$$

where m = mass of the rider

g = acceleration due to gravity

L = length of portion CD of wire frame

Measure the force of attraction for various values of current through the two wires. Thus check up if F is proportional to I, or I^2, or I^3. For this purpose plot log F against log I. The slope $\Delta\log F/\Delta\log I$ gives the value of index of I. Alternatively, plot three graphs : F vs I, F vs I^2 and F vs I^3.

Estimate the spacing between the two wires, d, by looking at them against the mm-graph paper. Thus check whether the force of attraction is equal to that obtained by the formula:

$$F = \frac{\mu_0 I^2 l}{2\pi d}$$

where μ_0=permeability of air=$4\pi \times 10^{-7}$ Tm/A

I = current passing through the two wires and

l = length of the wires.

Notes : 1 Because field due to one wire at the other decreases near the ends, the force of attraction is slightly less than that obtained by the above formula.

2. It is difficult to make the two wires exactly straight and parallel Hence note their spacing, d, atleast 5 or 6 points along their length and find the average spacing. Inter-axial spacing is equal to spacing between top-boundaries of the two wires, if they are of equal diameter. This fact enables you to measure inter-axial spacing more easily.

3. Since this current balance is quite sensitive, care has to be taken that no mechanical disturbance (like draughts of wind) is present during the experiment.

3.20 (Experiment) : To compare the strength of two magnets (magnetic moments) by deflection magnetometer.

Apparatus . Deflection magnetometer, two short strong bar magnets of equal dimensions, spirit level

Procedure · Adjust the circular scale of magnetometer so that the line joining the zero-zero marks coincides with the common axis of the two arms Then adjust the whole instrument so that the two ends of the aluminium pointer

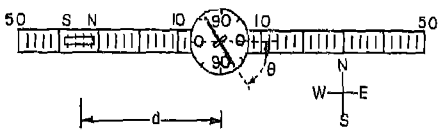


Fig. 3.29 *Measuring deflection of the deflection magnetometer produced by a magnet*

(which makes the east-west direction) reads zero-zero on the circular scale.

In this case two arms are in the east-west direction (Fig. 3.29). Place one of the magnets, P, at a distance d from the centre, such that its geometric axis (which is presumed to be also the magnetic axis) is along the central line of the scales Note the scale readings at its ends. The mean of these two reading gives the distance, d of centre of the magnet from the centre of the magnetic needle.

The magnet produces a magnetic field, B, perpendicular to earth's magnetic field, H, at the centre of the magnetic needle. This field deflects the magnetic needle through angle θ such that

$$B = H \tan \theta$$

Note the reading θ_1, θ_2, of the two ends of the pointer. Reverse the polarity of the magnet, keeping it at the same position on the same arm, so that the magnetic needle is deflected in the opposite direction. Note the readings θ_3, θ_4 of the two ends of the pointer in the opposite direction. Put the magnet on the other arm at the same distance, d, and take four similar readings θ_5, θ_6, θ_7, & θ_8. Find the deflection,θ as mean of the eight readings. This deflection may be taken as the deflection caused by the magnetic field of the magnet at a distance, d. You will appreciate from the following, the reason why you should take the mean of eight readings to give you correct deflection

You should read two ends of the pointer because it is likely that the pivot on which the magnetometer needle is supported may not be at the centre of the circular scale (Fig. 3.30).

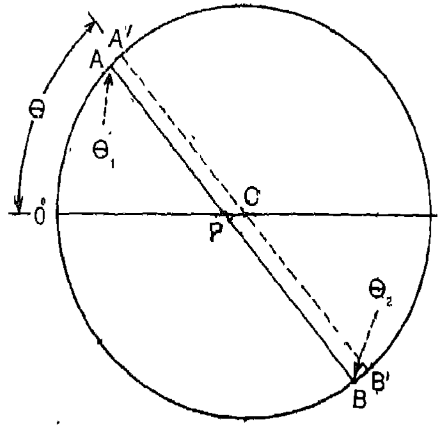


Fig. 3.30

In such a case, one end of the pointer will give larger deflection whereas the other end will read smaller deflection. C is the centre circular scale and P is the pivot. If the pivot were correctly at C, then the pointer would have been along the dotted line A'B'. However, because P is not at C, the pointer is along AB. Thus it reads deflection θ_1 (= arc OA) at one end and θ_2 (= arc OB) at the other end. The correct deflection θ is the mean of θ_1 and θ_2. Thus it is necessary to read the two ends of the pointer to remove the possible error that may be caused by the possible error in the position of P.

You have placed the magnet at a distance d from the centre of the circular scale. You measure this distance between the geometric centre of the magnet and the centre of the circular scale. In fact you should measure the distance between the centre of circular scale and the magnetic centre of the magnet, which may not

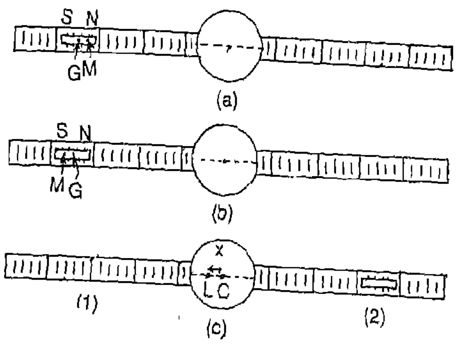


Fig. 3.31 (a, b, c)

be necessarily at the geometric centre of the magnet. As shown in Fig. 3.31a, G is the geometric centre and M is the magnetic centre. In this case the real distance CM is less than the distance d (=GC). This will give a deflection greater than what would be obtained if CM was equal to d. Now if you reverse the magnet end to end, you will make CM greater than GC. In this case you will observe a deflection smaller than what would be obtained if CM was equal to d'(Fig. 3.31b).

You take similar four readings by placing the magnet on the other arm. This is necessary to avoid the error that may creep in because of the likely displacement of the centre of the linear scale on the arms of the magnetometer and the centre of the circular scale as shown in the Figure 3.31c (C is the centre of the circular scale and L is the zero of the linear scale on the arms of the magnetometer. Normally, L and C should be coincident. When you place the magnet on arm 1 of the magnetometer at a distance d, the real distance is $(d + x)$, where x = LC. When you place the magnet on the other arm, the real distance is $d - x$. Thus in the first case the deflection is less than what you should have got, whereas in the second case, the deflection is more than what you should have got.

In this manner determine the deflections θ_p for various values of d, say, 15 cm, 20 cm, 25 cm and 30 cm for first magnet P. The distances should be such that θ_p lies in the range 25° to 65°. Then find the deflections θ_q for same values of d for the second magnet Q. Values of d being same for the two magnets and both

Observations:

Distance, d (cm)	Magnet	Deflection								Mean θ	$\frac{M_p}{M_q} = \frac{\theta_p}{\theta_q}$
		Magnet on East arm				Magnet on West arm					
		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8		

being of same size. The magnetic fields produced by them, B_p and B_q are proportional to their magnetic moments M_p and M_q i.e.

$$\frac{M_p}{M_q} = \frac{B_p}{B_q} = \frac{\tan \theta_p}{\tan \theta_q}$$

Determine the ratio M_p/M_q with the help of observations for θ_p and θ_q at each distance and calculate the average value of this ratio.

Note · 1. It is important in this experiment that deflection magnetometer is kept at the same place while working with the first magnet and while working with the second magnet. If its location changes within the laboratory, it may cause error in the result. The reason is that due to so much iron used in the construction of the school building and due to an iron cupboard nearby, resultant of the magnetic fields due to earth and these iron objects may be different at different points in the laboratory.

2. Since the ratio of magnetic moments is obtained in terms of tan θ, we must see that fractional error in tan θ (i.e $\Delta \frac{\tan\theta}{\tan\theta}$), due to error $\Delta\theta$ in measurement of θ should be small. We know

$$\frac{1}{\tan\theta}(\Delta \tan\theta) = \frac{\sec^2\theta \, \Delta\theta}{\tan\theta}$$

$= 2 \ \text{cosec} \ 2\theta\Delta\theta.$

Figure 3.32 shows variation of cosec 2θ against θ. You will notice that this error is the smallest for θ = 45° and is tolerably small if θ lies between 25° and 65°.

3. You can find the ratio of the magnetic moment of the two magnets in yet another way, which is given in the next experiment.

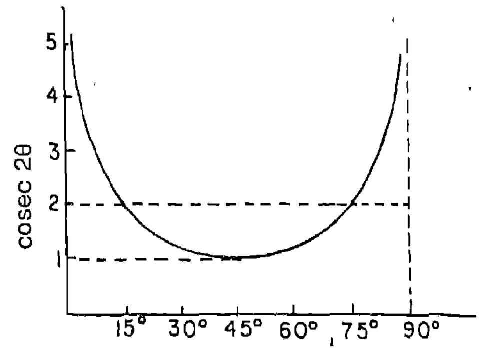


Fig. 3.32 *Percentage error in the result of deflection magnetometer due to some error in measuring is minimum at θ = 45° Values of θ should be kept between 25° & 65°*

3.21 (Experiment) To compare the magnetic moments of two magnets by oscillating them in the earth's magnetic field.

Apparatus: Two strong bar magnets, oscillation magnetometer (an aluminium wire stirup suspended by an unspun silk thread in a closed box as shown in Fig. 3.33 a), stop watch, vernier cal-

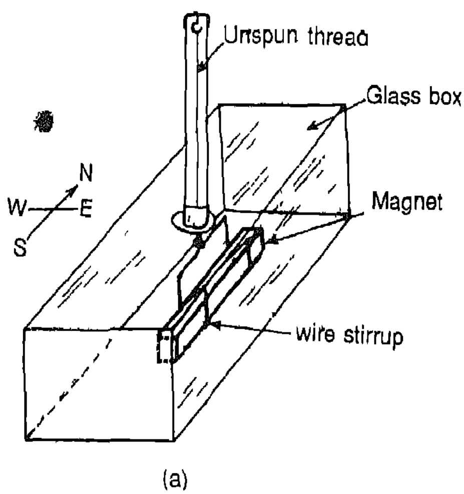


Fig. 3.33 *The oscillation magnetometer*

lipers, physical balance in which no part is made of a feromagnetic material)

Theory: If a bar magnet is free to rotate in a horizontal plane, it comes to rest along the magnetic north-south direction. In Fig. 3.33b, th axis of rotation is perpendicular to the plane of the paper. Suppose you displace this magnet by rotating it through an angle θ to occupy the position N' S' (Fig. 3.33b). Then the magnet

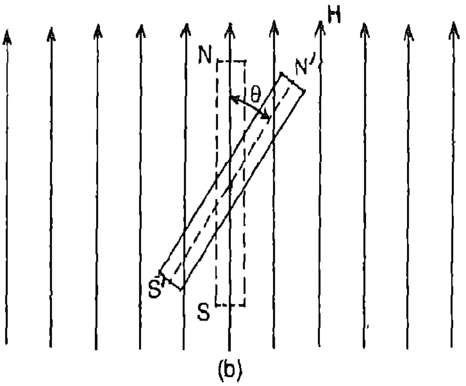


Fig. 3.33 (b)

will experience a couple $MH \sin\theta$ tending to take it back to its original position NS. In so doing, it overshoots the mark. Again the couple acts to take it back to its original position. Thus the magnet oscillates. Its angular acceleration at a displacement θ is given by

$$I \frac{d^2\theta}{dt^2} = - M\ H \sin\theta$$

If θ is small, sin θ may be taken as θ, i.e

$$I \frac{d^2\theta}{dt^2} = - M\ H\ \theta$$

This is a simple haromonic motion with a periodic time T.

$$T = 2\pi \sqrt{\frac{I}{MH}}.$$

where M is the magnetic moment of the magnet,

H is the horizontal component of earth's magnetic field and I is the moment of inertia about the vertical axis of rotation. With a rectangular bar magnet of length a and breadth b, the moment of inertia about an axis perpendicular to ab-plane and passing through the centre is

$$I = m\ \left(\frac{a^2 + b^2}{12}\right)$$

where m = mass of the magnet

Procedure: First remove the twist in the suspension by allowing the stirrup to come to rest. Adjust the head from which stirrup hangs such that the stirrup is parallel to length of the box. Then rotate the box so that its length is along north-south direction.

Now place one of the magnets P (its N-pole pointing north) on the stirrup, which is also along the N-S direction. Bring the north pole of the other magnet, Q, close to north pole of the suspended magnet for a while and remove it. Because of the repulsion between the north poles of the two magnets, the magnet P deflects and then starts oscillating about the axis corresponding to the suspension thread and under the influence of earth's magnetic field. Observe through the glass on top of the box, the image of the magnet in the mirror placed at the bottom of the box. Thus observe the instant of its each transit through the mean position for measuring the time. With the help of a stop watch measure the time it takes to make 20 oscillations. Thus find the time period of oscillations, T_p Repeat these measurements by second magnet now, replacing it in the same stirrup and find the time period of its oscillations T_q.

With the help of vernier callipers measure length and breadth of each magnet (i.e. the sides perpendicular to the suspension thread). Also find the mass of each by the physical balance. Thus find their moments of inertia, I_P and I_Q.

Then calculate the ratio of their moments of inertia using the relation

$$\frac{T_P^2}{T_Q^2} = \frac{I_P}{I_Q}\frac{M_Q}{M_P}, \text{ or } \frac{M_P}{M_Q} = \frac{I_P}{T_Q}\frac{I_P}{I_Q}$$

If these magnets P and Q are same as those used in the previous experiment, compare your results in the two experiments.

Observations:

(A) Moment of Inertia

Magnet	Mass m (Kg)	Length a (m)	Breadth b (m)	Moment of Inertia, I (Kg m^2)

(B) Time period of oscillations in earth's magnetic field.

Magnet	Time taken for 20 oscilations(s)					Time Period T (s)
	1	2	3	4	Mean	

$$\frac{\text{Magnetic moment of magnet P}}{\text{Magnetic moment of magnet Q}} = \frac{T_q^2}{T_p^2}\frac{I_p}{I_q}$$

Notes: 1. If the physical balance has any part made of iron or any other ferromagnetic material, the mass of magnet measured in it may have error, due to its force of attraction with that part. Force that the magnet exerts on any paramagnetic or diamagnetic substance is, however, negligible for this experiment.

2. It is important in this experiment also to keep oscillation magnetometer at the same place while working with both the magnets so as to ensure the same value of H.

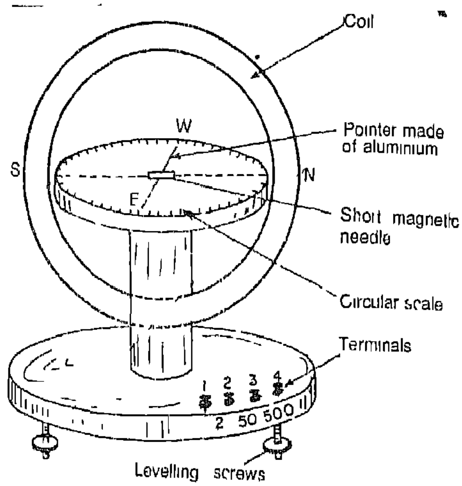


Fig. 3.34 *The tangent galvanometer*

3.22 (Demonstration): To demonstrate a tangent galvanometer and show its working:

The tangent galvanometer consists of a deflection magnetometer placed at the centre of a coil in which current can be passed By choosing appropriate terminals any number of turns, 2 or 50 or 500, can be used (Fig. 3.34). The greater the number of turns used, the smaller is the current by which it can be operated.

With the help of levelling screws and a spirit level, the circular scale of deflection magnetometer is adjusted horizontal. Then the coil is in a vertical plane and can be rotated about a vertical axis passing through its centre, which is also the centre of the magnetic needle of the magnetometer. For working with it, the coil is adjusted by rotating it about the vertical axis till its plane is in the magnetic meridian. Then magnetic needle is in the plane of the coil and pointer is perpendicular to it. To observe the deflection of the coil, circular scale is rotated till the 0° - 0° line coincides with the pointer

Then on passing the current, the magnetic field, B due to current passing through the coil

Observations:

S.No.	Series resistance (Ohm)	Cell	Magnetometer Deflection					tan θ	$E_L/E_D = \frac{\tan \theta_L}{\tan \theta_D}$
			θ_1	θ_2	θ_3	θ_4	Mean θ		

is towards east or west, and its magnitude is

$$B = \frac{\mu_0 N I}{D}$$

Where N = number of turns in the coil

D = mean diameter of the coil

$= \frac{\text{I. D.} + \text{O.D.}}{2}$

I = current passing through the coil, and

μ_0 = permeability of medium (air) $\approx 4\pi \times 10^{-7}$ Tm/A.

The magnetic field produces a deflections θ of the needle.

$$\tan\theta = \frac{1}{H}\,\frac{\mu_0 I}{D}$$

Where H = horizontal component of earth' magnetic field at the magnetic needle.

Because current is proportional to tangent of the deflection, hence it has acquired the name *tangent galvanometer*. This galvanometer can be used to measure current only if H is known and was so used in the past. However, in the S I. system of units, current is the fundamental quantity and magnetic field is measured in terms of the current.

3.23 (Experiment) To compare the e.m.f's of two cells by using a tangent galvanometer

Apparatus. Two cells (one Leclanche cell and the other Daniell cell), tangent galvanometer,

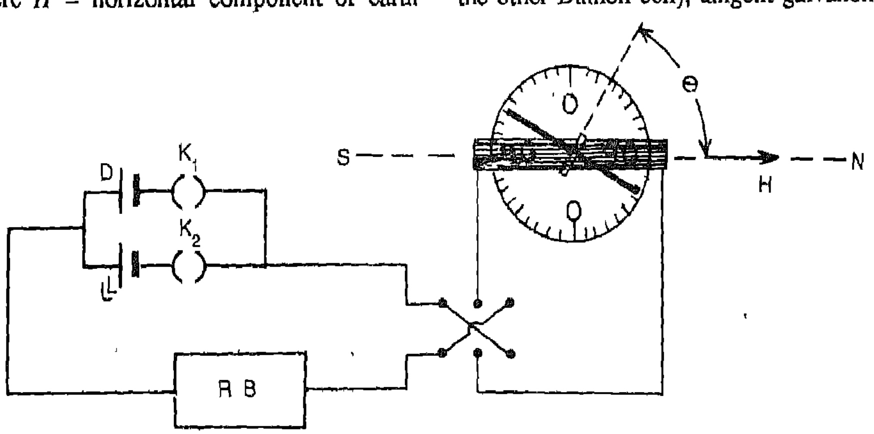


Fig. 3.35 *Electrical circuit for comparing the emf of two cells by a tangent galvanometer*

resistance box, commutator, two way key

Procedure: Adjust (i) the circular scale of tangent galvanometer horizontal, (ii) its coil in the magnetic meridian ad (iii) the 0°-0° diameter of circular scale to coincide with aluminium pointer. Connect the 500-turns terminals to the commutator and complete the circuit as shown in (Fig. 3.35). D and L are the Daniell ad Leclanche cells, any one of which can be used to pass a current by closing the appropriate key

Insert a suitable resistance in the circuit so that the deflection of the needle is between 25° and 50° with the Daniel cell Read the deflection of magnetic needle with the help of the pointer. Reverse the current and again read the deflection marked by the two ends of the pointer. Mean of these four readings give the value of θ_D, the deflection of the magnetic needle by the current which passes in the circuit by Deniell cell Similarly find θ_L, the deflection by Leclanche cell, keeping circuit resistance same. Then according to Ohm's law:

$$\frac{\text{E.M.F. of cell D}}{\text{E.M.F. of cell L}} = \frac{\text{Current by cell D}}{\text{Current of cell L}} = \frac{\tan \theta_D}{\tan \theta_L}$$

In this calculation we treat the internal resistance of the cells to be negligible compared to resistance in the resistance box, and thus the total circuit resistance to be same in both cases.

Take various values of resistance in the resistance box, for each resistance measure θ_D and θ_L and calculate the ratio of e.m.f.'s

Notes: 1. In this experiment it is necessary to use the largest number of turns available in the galvanometer. Thus only a small current produces a deflection between 25° and 65° and we are able to use a high resistance in the resistance box.

2. The observed deflection depends on the value of the restoring field which is essentially earth's magnetic field, which should not change throughout the experiment. Carry out the experiment with both the cells at the same place to ensure that the restoring field H is the same in both the cases

3.24 (Experiment): To measure an unknown resistance by using a tangent galvanometer.

Apparatus. The tangent galvanometer, the unknown resistance, a resistance box, two way key, rheostat, accumulator

Procedure: Adjust the galvanometer as described in demonstration 3.22. Make the connections as shown in figure 3.36. In position 1

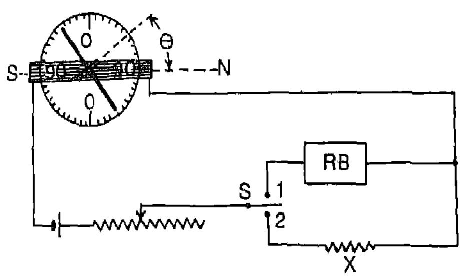


Fig. 3.36 *Electrical circuit for measuring a resistance X by tangent galvanometer.*

of the two way switch, S, the resistance box, R.B., is connected in the circuit. In position 2 of the switch, the unknown resistance X gets connected in the circuit.

Bring S into position 2 first to bring X in the circuit. Adjust the rheostat so that the deflection is around 45°. Note the reading at two ends of the pointer. Next, bring S into position 1, bringing the resistance box in the circuit. Make suitable resistances in the R.B. so that the deflection is between 25° and 65°. Note the each value of resistance in R.B. and the corresponding deflection by reading both the ends of the pointer. Plot a graph between deflection and the resistance in the resistance box. Then from this graph find out the value of X, corresponding to

the deflection which was noted with X in the circuit.

3.25 (Demonstration): To demonstrate that a current carrying conductor experiences a force in a magnetic field.

A simple, Barlow's wheel very effectively demonstrates this concept. Fig. 3.37 schematically shows this apparatus. It essentially consists of a metallic wheel, W, free to rotate about its centre, keeping its plane vertical. Terminal T_1 is connected to its centre through the stand in which wheel is supported. Below the lowest point of the wheel is placed a wooden block B, in which there is a drop of mercury in a small pit. Lowest point of the wheel dips in mercury. A connection wire is joined to terminal T_2 in the block so that its one end dips in mercury. A battery B and key K are connected across T_2 and T_1. Then on closing the key, a current passes in the wheel from centre to mercury drop.

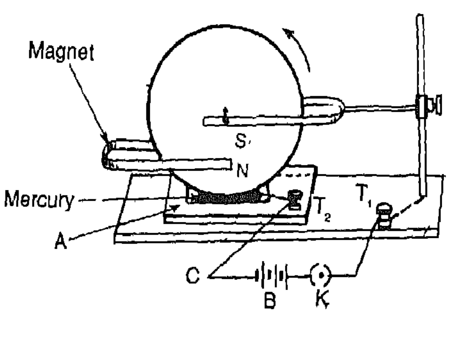


Fig. 3.37 *The Barlow's wheel*

On bringing a strong horse-shoe magnet such that it produces a magnetic field parallel to axis of the wheel in the region where current is passing, you observe that wheel starts rotating. The wheel continues to rotate as long as current is passed as well as magnetic field exists in the region where current is passing. After observing the motion of the wheel, check that the force experienced by the current in the wheel is in accordance with the Fleming's left hand rule (Fig. 3.20).

3.26 (Demonstration): To demonstrate the working of a moving coil galvanometer and use it to compare the e.m.f's of two cells.

The most useful equipment for this demonstration is the demonstration model of a moving coil galvanometer, which is commercially available at moderate cost. Fig. 3.38 shows the essential parts of a moving coil galvanometer, which can be easily seen by students in a group in the demonstration model.

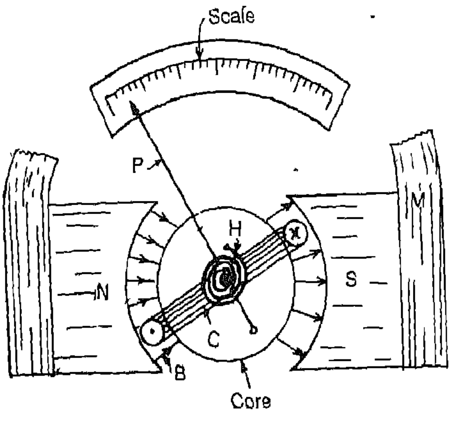


Fig. 3.38 *The construction of a moving coil galvanometer*

There is a strong parmanent horse-shoe magnet M with concave cylinderical pole-pieces N and S. Coaxial with the pole-pieces, there is a cylinderical soft iron core. Thus in the space between the core and pole-pieces a radial magnetic field is produced, i.e. the lines of magnetic flux point towards the common axis of the pole-pieces and the core. Then the force

F, acting on the vertical sides of the coil C of mean area A moving in this radial field of flux density B are always at right angles to the coil, thus producing a constant maximum torque = $BINA$, where I is the current passing in the coil and N is the number of turns in the coil. The coil settles down in deflected equilibrium position, when this deflecting torque due to current in the coil equals the restoring torque of the hair spring H. The restoring torque, due to its elastic nature, is proportional to angular deflection α of the coil, which is measured by the pointer P, moving on the scale

Let the restoring torque per unit deflection of the coil (i.e. one division rotation of pointer on the scale) be C newton-meter. If the coil turns through α scale divisions to reach its equilibrium position, then

$$BINA = C\alpha$$
$$\text{or } \alpha = \frac{BINA}{C}$$

Following conclusion immediately follows from this relation:

(a) For a given galvanometer, the current is proportional to deflection α. This is in sharp contrast to tangent galvanometer where current is proportional to tangent of deflection. Thus the scale in this instrument is linear, which makes it very convenient to use. Sensitivities of such instruments are up to 1 mm per μA, i e. the deflection of the pointer on the scale is 1 mm for 1μA current passing through the coil. When an instrument is used for adjusting a null point, as in a Wheatstone bridge, the sensitivity in terms of voltage across the coil is important. Voltage sensitivity of such instrument are upto 2mm per mV. Higher sensitivities are achieved by (i) arangements with low value of C (phosphor bronze band suspension instead of a hair spring) and (ii) more sensitive arrangements to measure deflection (lamp and scale arangement)

To demonstrate the working of this galvanometer, you can do a simple experiment to compare the emf of a Leclanche cell with that of a Deniell cell. The connections to be made and procedure to be followed are idential to those in experiment 3.23, (illustrated in Fig. 3.35) if your galvanometer has zero-mark in centre of the scale (as it usually is) The formula to be used for calculations, however, is different:

$$\frac{\text{E.M.F. of cell D}}{\text{E.M.F. of cell L}} = \frac{\text{Current by cell D}}{\text{Current by cell L}} = \frac{\theta_D}{\theta_L}$$

3.27 (Activity): To make a simple D.C. motor.

Make a simple motor which uses current from a battery to excite the field magnets as well as the armature coil.

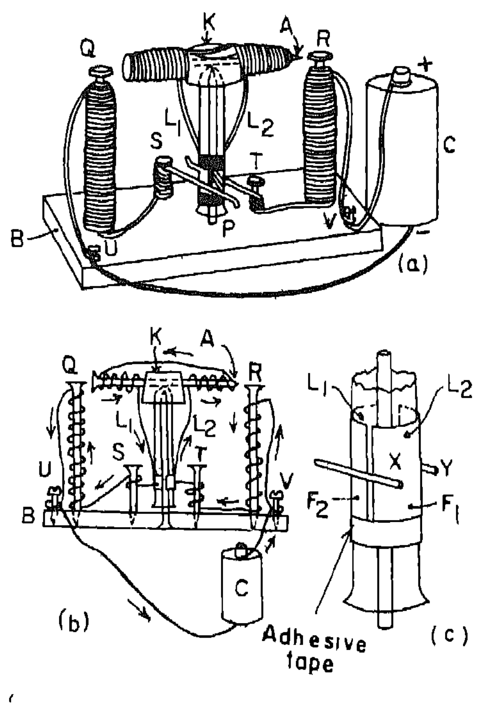


Fig. 3.39

Prepare a base board B, of size 20 cm x 25 cm (Fig.3.39). Drill a small hole thorugh the centre an drive a 15 cm nail P up thorugh it. Wind about 200 turns of enamelled copper wire (22 SWG) on two other 15 cm nails, Q and R, leaving about 30 cm of wire for free ends. Drive these nails into the board 15 cm apart

Drive two small nails S and T, on the diagonal of the base board and 5 cm from the nail at the centre. Remove enamel at the free ends X and Y, of each coil and twist them several times around the nails S and T respectively and bend them so that they will rest in contact with the central nail P These ends will serve as brushes. Care must be taken to have the field coils wound in proper direction Fig.3.39 a, b and c show a complete plan for the direction of windings. It will work in no other way. The other ends of the coils may be fastened to screws U and V in the corners of the base. Your field magnets and brushes, two of the four essential parts of a motor are now complete.

The armature coil and commutator are now to be constructed. Drill a hole crosswise through the top of a 4 cm cork and force a 13 cm nail, A through it. Wind about 40 turns of enamelled copper wire on to each end, making sure the direction of windings is as shown. Scrape the free ends L_1 and L_2. Now gouge out the centre of the cork neatly round with a pen knife and insert th closed end of a 10.5 cm or 13 cm test tube into the cork. This completes the armature coil.

You are now to make the commutator. Cut out two rectangular pieces of sheet copper about 4 cm long and wide enough to reach around the test tube with about 5 mm space between them. Curve these to fit the tube. Punch small holes in the copper sheet pieces and into each hole, twist one of the scraped free ends L_1 and L_2 of the armature windings. Then bind these commutator plates securely into position at top and bottom with adhesive tape. Your rotor, consisting of armature and commutator, is now complete.

Set the rotor into position on the central vertical nail and bring the brushes into contact with the commutator. Now if your windings and connections are all as shown, connect the free ends of the field coils to a cell C. Then with a slight push of the armature, it should start rotating at a lively speed.

Notes: 1. Just in case your armature does not keep rotating, examine the brushes to see whether they make a light but certain contact.

2. Another crucial issue for success of your motor is the angle of the brushes To ascertain the correct angle at which brushes should make contact with the commutator, untwist the brushes from the nails and hold them lightly against the commutator plates with the fingers While holding them alwys parallel, swing them around at different angles, while another colleague turns the armature with his hands. Note the point at which the armature picks up most speed and then set the brushes at that point. With a little patience you are sure to be successful.

TOPIC III EARTH AS A MAGNET

3.28 (Demonstration): To show that the earth's magnetic field has both vertical and horizontal components.

Horizontal Component · Take a compass needle. Place it horizontally on the pointed support so that it is free to rotate in a horizontal plane. You find that it comes into equilibrium along north-south direction only. If you leave it in any other position, it moves to north-south direction Clear implication is that forces are acting on its poles as shown in Fig. 3.40. Hence earth's magnetic field is capable of applying a force in a horizontal plane towards north direction on the north pole of the compass needle and an

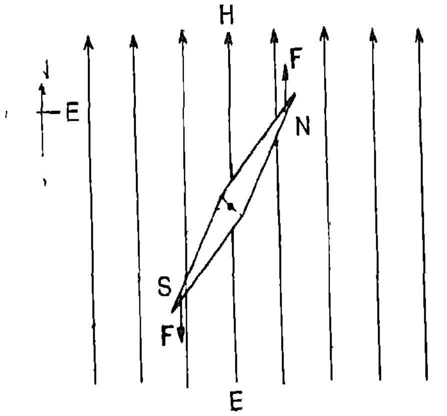


Fig 3.40 *A compass needle experiences forced F F in horizontal plane in the earth's magnetic field*

equal opposite force on the south pole. Hence it has a horizontal component.

Vertical Component: Take a dip needle. It is a compass needle free to rotate in a vertical plane. Its horizontal axle about which it rotates, passes through its C.G. Thus gravitational force has no tendency to keep it in any preferred direction. The needle and its frame can rotate about a vertical axis so that its vertical plane of rotation can be set in any direction (Fig. 3.41). A 90° circular scale is also attached to the frame on which one can observe at what angle to horizontal the needle comes into equilibirum.

Keeping the vertical plane of rotation of the needle in north-south direction (i.e. in magnetic meridian), observe the reading of the needle on the circular scale. Repeat this observation keeping the plane of rotation at various angles to magnetic meridian. You observe that when the plane of rotation is along east-west direction, the readingis largest i.e. 90° making the needle vertical (Fig. 3.42b). In this position the vertical component of earth's magnetic field pulls the north pole of needle downwards and pushes the south pole upwards and the horizontal component is ineffective (because forces F applied by it on the poles of the magnetic needle are perpendicular to the plane of rotation of the needle as shown in Fig. 3.42a).

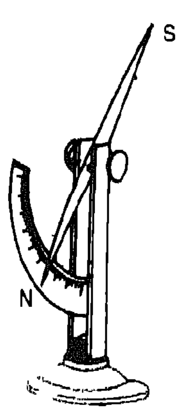


Fig. 3.41 *The dip needle*

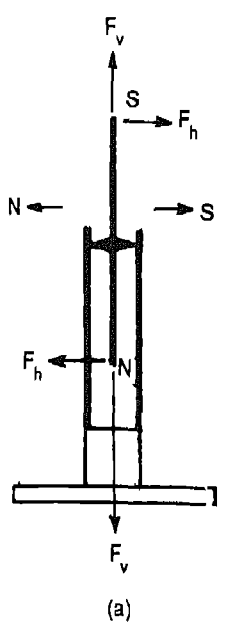


Fig 3.42 *Dip needle becomes vertical when its plane is the East-West Asia direction*

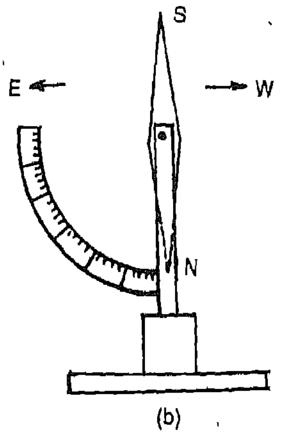


Fig. 3.42(b)

When the plane of rotation is in magnetic meridian, you observe that the reading on circular scale is smalles. (Fig. 3.43a). In this position the horizontal component of earth's magnetic field is fully effective and the needle points in the direction of the resultant magnetic field. The reading on the circular scale in this position is called *angle of dip*.

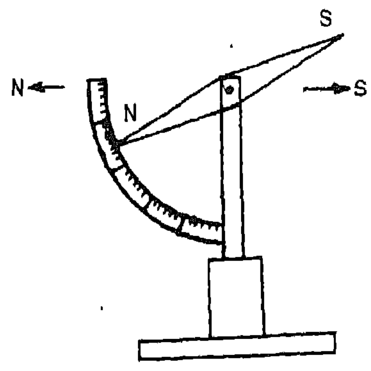


Fig. 3.43 *In the magnetic meridian, the dip needle reads the angle of dip*

Note: 1. The north direction indicated by the compass is usually not the geographic north direction. The angle between the two directions is called *angle of declination*. Only if you know this angle, you can find geographic north direction with the help of a compass

2. The vertical component of earth's magnetic field and angle of dip can also be demonstrated with the help of dip circle which is a more elab orate instrument and is explained in experiment 3.31. Conversely, that experiment can also be done (with less accuracy in the result) using the dip needle.

3.29 (experiment): To determine the horizontal component of earth's magnetic field using a tangent galvanomete.

Apparatus. Tangent galvanometer, commutator, ammeter, battery, plug key, rheostat

Procedure. Adjust the galvanometer such that the circular scale is horizontal the coil is in magnetic meridian and pointer reads 0°-0° with no current in the coil. Complete the circuit as shown in fig. 3.44. Choose a suitable

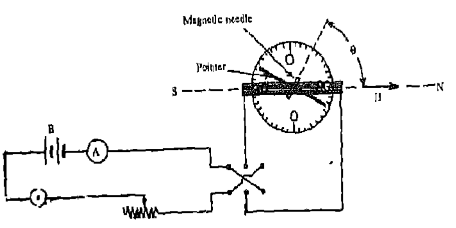


Fig. 3.44 *Electrical circuit for measuring the horizontal component of earth's magnetic field by a tangent galvanometer*

pair of terminals on the tangent galvanometer and adjust current by rheostate such that (i) ammeter reading is more than half of its full scale deflection and (ii) deflection of tangent galvanometer is between 25° and 65°.

Now pass the current in one direction. Then read the current, I in ammeter and deflection of both ends of the pointer (θ_1, θ_2) Reverse

the current and again read the deflection of both ends of the pointer (θ_3, θ_4) Calculate the deflection, θ, of the pointer as mean of these four readings. Repeat the readings of various values of current which deflect the magnetic needle of the magnetometer through 25° to 65°. Plot a graph between I and tan θ, taking the former along X-axis and the latter along Y-axis—a straight line through the origin

Find the slope of the graph:

$$\text{Slope} = \frac{\text{Change in } \tan\theta}{\text{Change in } I} = \frac{\mu_0 N}{DH}$$

Take at least two perpendicular readings, measure the inner and outer diameters of the coil and find the mean diameter, D

Thus find the value of earth's magnetic field, H·

$$H = \frac{\mu_0 N}{D\ (\text{slope})}$$

Observations:

Internal diameter of the coil =

(i) ________ m (ii) ___________ m

Mean I.D. = ___________ m

Outer diameter of the coil =

(i) ________ m (ii) __________m

Mean O.D. = _____________ m

Mean diameter of the coil, D

$$= \frac{\text{I.D.} + \text{O.D.}}{2} = \_\_\_\_\_\_\_ \text{ m}$$

Number of turns of the coil used, N = ______

$$\text{Slope} = \frac{\text{Change in } \tan\theta}{\text{Change in } I} = $$

Earth's magnetic field, H

$$= \frac{4\pi \times 10^{-7} N}{D \times \text{Slope}} = \_\_\_\_\_\_ \text{ T}$$

Notes: 1 The coil should be connected to the reversing key by a long piece of twin flexible wire, so that the ammeter and the connecting wires carying the current exert no appreciable magnetic field on the needle of the tangent galvanometer.

2. Because, nearly all sensitive ammeters are for use with direct current and have their zero mark at the left end of the scale, it is essential that the ammeter should be connected on the battery side of the reversing key, as shown in Fig. 3.44.

3 Check the ammeter for zero-reading If necessary, reset it by the adjusting screw provided

4. Taking deflection θ as the mean of four readings θ_1, θ_2, θ_3, θ_4 is not just to reduce the random erro of observation. It eliminates errors due to :

(a) plane of the coil not being accurately in magnetic meridian, and (b) pin on which magnetic needle and pointer are suspended not being accurately in the centre of the circular scale of the deflection magnetometer

The reasoning as to how these errors are

Current, I (A)	Deflection of magnetic needle θ					tan θ
	1	2	3	4	Mean	

eliminated, is similar to that for deflection magnetometer, given in experiment 3.20

5. While noting the deflection of the pointer in the deflection magnetometer or while observing its zero-reading, the box should be gently tapped so that friction between the magnet and pin on which it is suspended, is minimised.

6. The precedure of finding internal diameter and outer diameter of the coil and finding their mean, gives only an approximate result. Since the coil is wound in layers one over the other, the mean diameter depends on the number of turns chosen. Figure 3.45 shows a portion of the

$$\text{or } \frac{M}{H} = \frac{d^3 \tan \theta}{2\mu_0} \quad \ldots\ldots(1)$$

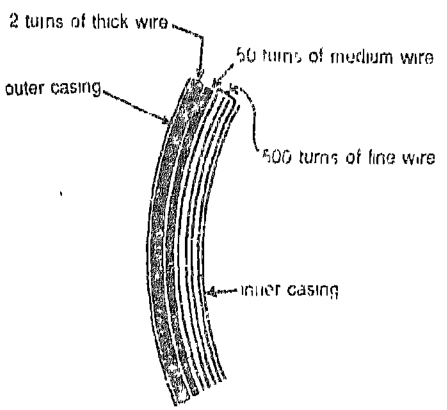


Fig. 3.45 *Details of layers of different windings in the coil of a tangent galvanometer*

coil and details of various layers of winding inside the coil. A good manufacturer of the instrument would specify the mean diameter for each number of turns that can be chosen. If this specification is available, it should be used.

3.30 (Experiment): To detemine the horizontal component of earth's magnetic field and magnetic moment of a magnet using a deflection magnetometer and a vibration magnetometer.

Apparatus: A short and strong bar magnet (an alnico magnet of 5 cm length and crossection 15mm x 10 mm is good) a deflection magnetometer, a vibration magnetometer, a stop watch, vernier callipers, physical balance.

Theory: If a magnet of magnetic moment M, produces deflection θ of deflection magnetometer in end-on position at a distance d, then

$$\frac{2 M \mu_0}{d^3} = H \tan \theta,$$

Where H is the horizontal component of earth's magnetic field, and μ_0 is the permeability of air ($4\pi \times 10^{-7}$T m/A). An important condition for validity of this relation is that d is much larger than length of the magnet.

If the same magnet oscillates in a horizontal plane due to earth's field with a time period T and its moment of inertia is I, then

$$T = 2\pi \sqrt{\frac{I}{M H}},$$

$$\text{or } M H = \frac{4 \pi^2 I}{T^2} \quad \ldots\ldots(2)$$

$$\text{From (1) \& (2), } M = \frac{2\pi}{T} \sqrt{\frac{I d^3 \tan \theta}{2 \mu_0}} \quad \ldots(3)$$

$$\text{and } H = \frac{2\pi}{T} \sqrt{\frac{2 I \mu_0}{d^3 \tan \theta}} \quad \ldots\ldots(4)$$

Procedure: Adjust the deflection magnetometer as explained in experiment 3.20 and in Figure 3.29. Find the deflection produced by the magnet for at least two distances, calculate $d^3 \tan \theta$ in each case and find its mean value. If you are using a 5 cm magnet, keep its distance from magnetic needle larger than 20 cm.

Next adjust the vibration magnetometer as

explained in experiment 3.21 and in Figure 3.33. Put the same magnet in the stirrup and find its time period of oscillation, T. Measure the dimensions and mass of the magnet and calcualte the moment of inertia I, as explained in experiment 3.21.

Then calculate the horizontal component of earth's magnetic field and magnetic moment of the magnet using the formulae given above.

3.31 (Experiment): To measure the angle of dip at a place with the help of a dip circle.

Apparatus. Dip circle, spirit level.

Description of apparatus: The dip circle (Fig. 3.46) is basically an improvement of the dip needle, which enables elimination of various experimental errors and measure the angle of dip accurately. In this instrument the circular scale is a full circle graduated into four quadrants, each having zero mark in horizontal direction and 90° mark in vertical direction. There are levelling screws to make the base and 0°-0° line of the vertical circular scale horizontal. The base also has a circular scale so that the plane of the vertical circular scale can be rotated about a vertical axis through any desired angle. The needle can be removed for reversal of the two ends of its axle, which rests on the knife edges to minimise friction.

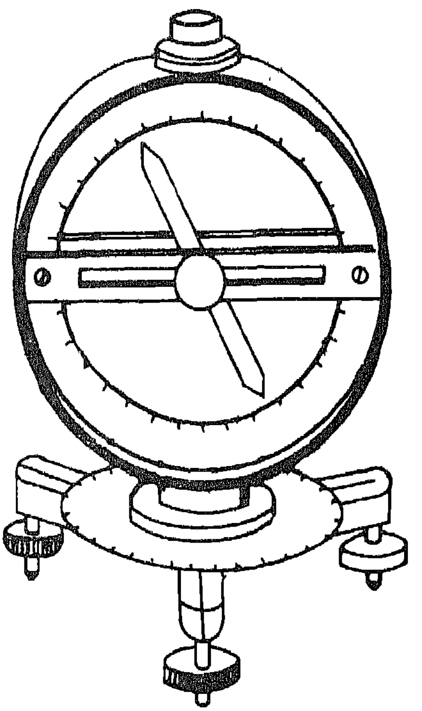


Fig. 3.46 *The dip circle*

Procedure: With the help of levelling screws and a spirit level placed on the base, make the base of the dip circle horizontal. Rotate the dip circle about a vertical axis till the magnetic needle becomes vertical. The plane of the rotation of the needle, which is also the plane of the circular scale, is now perpendicular to the magnetic meridian, i.e. in east-west direction. In this plane, the earth's horizontal field has no component.

Rotate the dip circle, now, through 90° on the horizontal scale, to bring it in the magnetic meridian. Observe the angle of dip at both the ends of the needle. Remove needle and place it back with the two ends of its axle interchanged and take readings at both ends of the needle. Next, rotate the plane of vertical scale through 180° and again take four more reading in similar manner. The mean of these eight readings is the correct angle of dip, eliminating the following errors:

1. *Axle of the needle may not be located accurately at the centre of the circular scale.*

Referring to figure 3.47a, X Y is the horizontal line, O is the centre of circular scale and O' the axle of the needle. If O' is on the left of O then angle S O' Y and N O' X are equal being vertically opposite angles and represent the correct angle of dip but, the scale reading at S (arc SY) is greater than that at N (arc NX). It can be seen easily that mean of the two readings will be more closely equal to angle S O' Y.

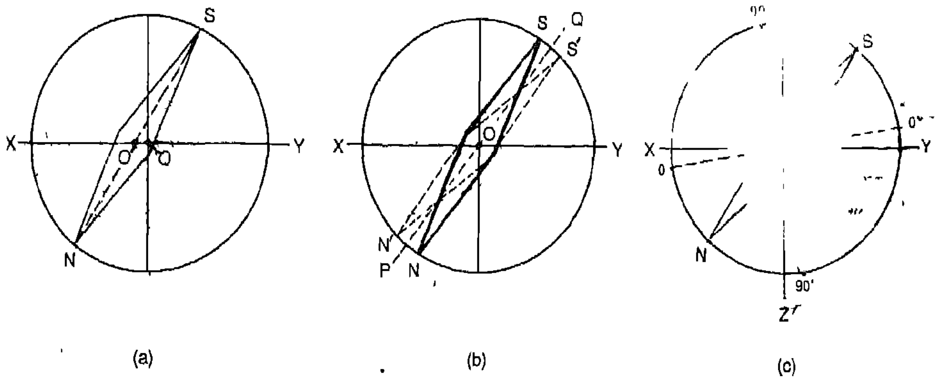


Fig. 3.47

2 *Geometric axis of the needle may not accurately coincide with its magnetic axis.* Then, as shown in figure 3.47b, magnetic axis, PQ, remains in the direction of earth's magnetic field but geometrical location of tips N and S of needle may give a larger angle of dip (for example). On interchanging the two ends of its axle the magnetic axis is, again, along line PQ, but the tips of the needle in position N' and S' give an angle of dip smaller than actual one, and +ve and -ve errors in the two cases are equal. Hence they cancel in taking the mean of the two sets of observations

3. *0° - 0° line of vertical scale may not be accurately perpendicular to vertical axis about which it rotates* Thus, it may not be horizontal (Fig. 3.47c). This it is a small mechanical fault which may occur while making the instrument. In this figure ZOZ' is the vertical axis and X'OY' is the horizontal line. The 0°-0° line, XOY is such that the observed value of angle of dip (i.e. arc XN) is too small. When the entire instrument is rotated through 180° about the axis ZOZ', This 0°-0° line takes a new orientation in which the obseved value of angle of dip is too large. By taking the mean of these two sets of observations, this error is eliminated.

3.32 (Activity): To detect a concealed magnetic body (e.g. a standard one-kilogram weight of iron) by plotting the lines of force.

Place a large white sheet of paper on the table. Over this paper support a drawing board on four wooden blocks of height equal to that of one-kg. weight, keeping the one-kg weight in its centre and below it. Keep the longer edge of the board along north-south direction with the help of a compass. Take a few points A, A_1, A_2, A_3, A_4....on the southern short edge of the paper fixed on it. Starting form each point, plot a line of force by using a plotting compass.

Observe that the lines of force come closer together at the place whee the one-kg. weight is placed (Fig. 3.48). From the symmetry of the lines of force mark the point about which lines of force are symmetrical. This point should be the centre of the 1 kg. weight placed below. Note the distances of the point of symmetry so marked, from the four edges of the drawing board.

To check up how far you have correctly located the concealed 1-kg. weight, mark the for edges of the board on the large white sheet of paper placed on the table. Also mark the boundary of the 1-kg. weight placed on it. Locate the centre of the weight and measure its distances from the four edges of the board and

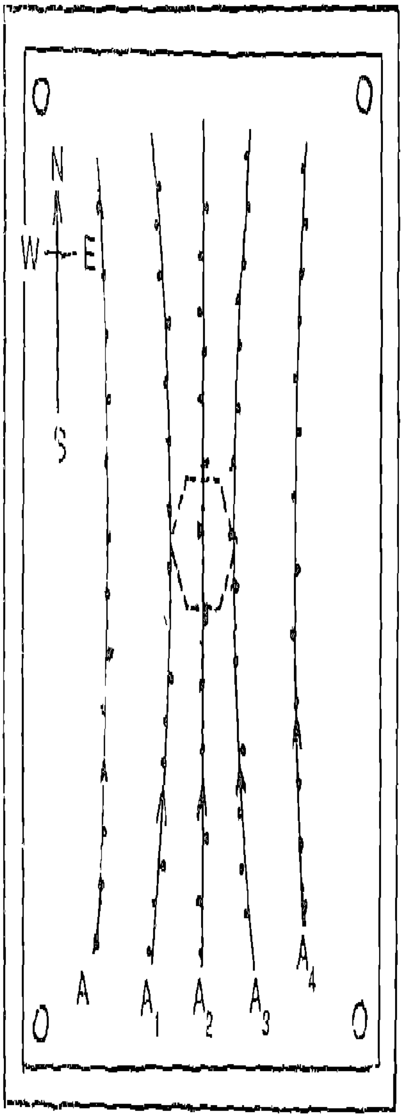


Fig 3 48

compare with the distances obtained from the magnetic field

Note You see in this activity that by a study of the magnetic field it is possible to locate the position of the concealed magnetic body In similar manner a sensitive magnetic survey over a vast area of land can reveal whether there is a deposit of iron and where it is located.

Electromagnetic Induction and Varying Currents

You have so far studied effects of electric current which occur whether the current is steady or is varying. In the present theme you will study an effect of current which is specifically associated with variation. When the current is varying, it produces a changing magnetic field, which in its turn induces an e.m.f. in the conductors through which the magnetic lines of force pass. This e.m.f. is induced whenever the magnetic flux through the conductor changes, whatever be the machanics of this change, and this phenomenon is called *electromagnetic induction*.

TOPIC I: PRODUCTION OF INDUCED e.m.f BY A CHANGING MAGNETIC FLUX

4.1 (Demonstration): To demonstrate the production of induced emf in a coil due to the movement of a magnet towards and away from it.

Take a coil of DCC[1] copper wire with about 300 turns (diameter about 20 cm) and a strong 5cm long bar magnet. Connect the two ends of the coil with the terminals of a sensitive galvanometer[2] (Fig. 4.1). Hold the magnet in your

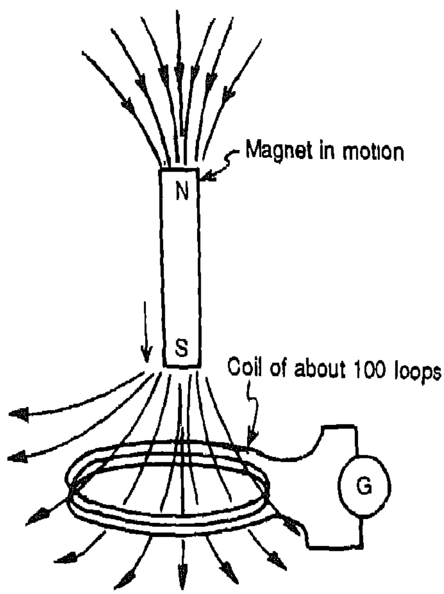


Fig. 4.1 *Magnet in motion produces an induced emf in coil S*

hand and bring it towards the coil. It may be inserted right into the coil. You will observe some deflection of the galvanometer needle, which is a measure of the induced current that flows due to an induced emf generated in the coil. Now you move the magnet away from the coil with roughly same speed. You will again observe same deflection, but now in oppposite direction. In the former case, the magnetic flux passing through the coil was increasing, while in the latter case it was decreasing. Note also that the deflection is observed only when the magnet is in motion It shows that the induced

[1]DCC means double cotton covered. Such a wire has two layers of cotton thread wound on it for insulation and is quite convenient for low voltage experiments in a school laboratory.

[2]It should give full scale deflection by less than 50 millivolt.

current flows as long as the flux is changing.

If you repeat the demonstration by moving the magnet faster you will observe greater deflection in each case It shows that higher the rate of variation of the magnetic flux, the greater the induced emf in the coil. This is a qualitative demonstration of the Faraday's law which states that the induced emf is directly proportional to the rate of change of flux.

4.2 (Demonstration): To demonstrate the production of induced emf in a coil due to the movement of similar coil carrying current towards and away from it.

Take the coil S used in the demonstration 4 1 above and connect it with the galvanometer (Fig 4.2) Take another coil P of same diameter and about 150 turns and connect it with an accumulater through a key The coil P acts as a magnet due to the current flowing in it Move this coil towards or away from the coil S as the magnet was moved in demonstration 4 1 above. You observe a deflection in the galvanometer, evidencing production of induced emf in coil S. If the coil P is moved faster, the deflection in the galvanometer is larger.

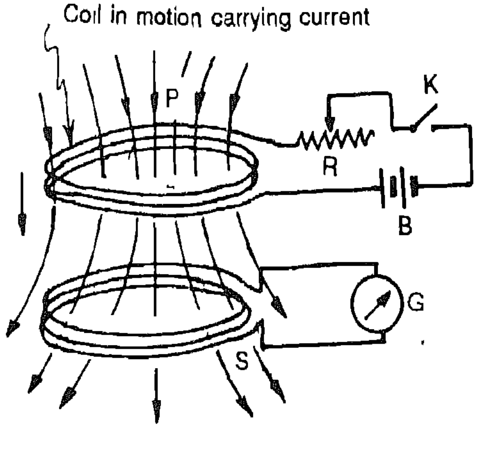


Fig. 4 2 *Current carrying coil in motion produces an induced emf in coil S*

Next, let us not move the coil P. Just place it on the coil S, separated by an insulator like a glass plate or a card board sheet Observe the deflection in the galvanometer connected to S as you switch on the current in P. Observe opposite deflection in galvanometer when you switch off the current in P. It is then clear that motion of the coil or magnet (Expt 4.1) is not the important factor It is the change of magnetic field produced by the coil P in the area occupied by S, which causes induced emf in the coil S.

Next, let the coil P be placed flat on a glass sheet, which in its turn is placed on coil S. The coil P carries a constant current and we do not change the current so that its magnetic field is also not changed Initially coil P is just above S, so that almost all the lines of force of P pass through S. Then slide P on the glass plate so that common area of the two coils decreases. Observe deflection in galvanometer in the same direction as that when current was switched off in P. Next, increase the common area and observe deflection in the same direction as that when current was switched on in P. So finally we learn that it is the flux of magnetic field produced by P and passing through S, whose change causes induced emf in S, whether this change is done (i) by motion of P which changes the field strength in S, and thus the flux of magnetic field through the coil S, or (ii) by change of current in P; or (iii) by change of area of P facing the coil S.

4.3 (Demonstration): To demonstrate the production of induced emf in a coil due to its motion in a magnetic field.

Take the coil used in demonstration 4.1 above and connect it with a galvanometer Move the

coil towards the space between the north and south poles of a strong magnet as shown in Fig.4.3 Observe the deflection in the galvanometer. Now take the coil away from the magnet and observe the deflection, which is in a direction opposite to the earlier one. Move the coil at a faster rate and observe the greater deflection. Note that the deflection is observed only when the coil is moving.

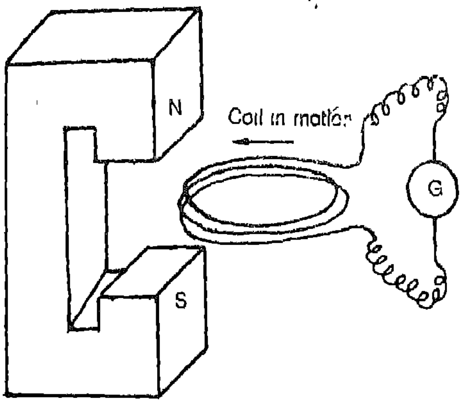


Fig. 4.3 *As the coil moves, induced emf is produced in it*

Here also it may be noted that whereas in the previous two experiments the coil connected to galvanometer was stationary, in this experiment it moves to cause a change of flux of magnetic field passing through it. When it moves into stronger field, the flux increases and when it moves away from stronger field, the flux decreases. Thus, change of flux passing through the coil, being the common feature in these three experiments is the primary cause of production of induced emf

4.4 (Demonstration): To demonstrate the production of induced emf in a coil due to its rotation in the Earth's magnetic field.

The coil required for this demonstration should be of about 20 cm to 30 cm diameter and made of insulated copper wire and should have between 500 to 1000 turns. It is fitted in a square frame so that it can be rotated suddenly through 180°, about an axis along its horizontal diameter (Fig 4.4). The coil rests on two pivots. Initially it is perpendicular to north-south direction i.e. in the E-W vertical plane. The two

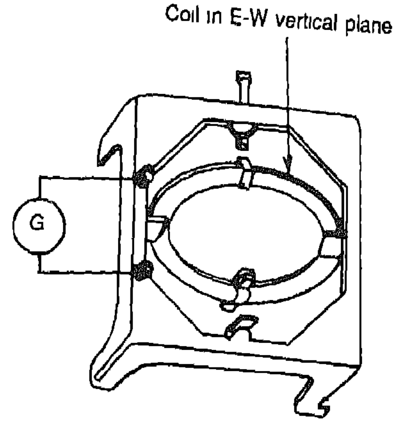


Fig. 4.4

ends of the coil of wire are connected to a sensitive galvanometer, (the kind used to study small thermo-emf's). The coil of a tangent galvanometer with 500 turns can also be used for this purpose, if you practice rotating it through about 180° in a time much shorter than the time in which needle/light spot of the galvanometer deflects.

If the coil is rotated in the Earth's magnetic field through 180°, the flux of the Earth's magnetic field passing through it decreases to zero during first 90° of rotation and then increases in opposite direction, reaching the initial

magnitude during next 90° of rotation. Thus an emf is induced in the coil. Therefore, some deflection is observed in the galvanometer.

A coil of this type is used to find the strength of the Earth's magnetic field (its horizontal and vertical components), and the angle of dip at a place. Such a coil is called an *Earth Inductor*.

4.5 (Demonstration): To demonstrate the production of induced emf in a coil placed in a solenoid, when current is passed or stopped in the solenoid.

Take a long (20 cm) solenoid made of thick copper wire (e.g. 22 SWG, enamelled) with 10 to 15 turns per cm and the coil diameter of 5 to 10 cm. It may be wound on the cardboard tube used for packing shuttle cocks. A slit of about 2mm width is cut in an arc of about 120° in the centre of the cardboard tube to insert a small coil into the solenoid.

Take another coil of thin copper wire (40 SWG) having about 100 turns and of diameter 2 cm less than that of cardboard tube. It can be inserted into the solenoid through the slit, as shown in Fig. 4.5. This coil is connected to a

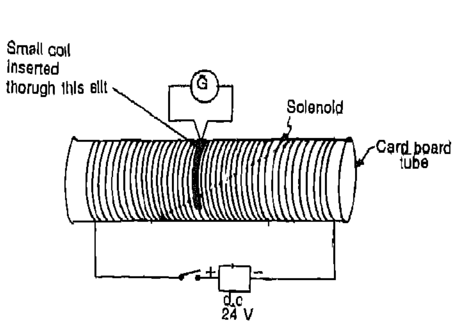


Fig. 4.5 *As the current is passed or stopped in solenoid, induced emf is produced in the small coil inside.*

sensitive galvanometer (the kind used to study small thermo-emf's.)

Connect the solenoid with a power supply through a tapping key. Apply a voltage of 24 V to the solenoid. You will observe a deflection in the galvanometer when the circuit is made or broken. However, the deflection obtained when the circuit is broken is in opposite direction to that obtained when the circuit is made The deflection is essentially due to the induced emf in the small coil, which results in the flow of current. This induced emf is produced by the changing flux of magnetic field inside the solenoid which passes through the small coil. By noting the deflection of the galvanometer and by using appropriate formulae, we can find the flux of the magnetic field passing through the small coil, and thus the flux density at its centre. A small coil so used is called a *search coil*.

4.6 (Demonstration): To demonstrate the production of induced emf due to motion of a straight conductor cutting across the lines of force in a magnetic field.

The apparatus required for this activity is shown in Fig. 4.6a. It consists of a horse-shoe magnet[3] and a metallic circular disc (2 mm thick and 15 cm diameter). The disc is placed between the two poles of the magnet as shown. The disc can be rotated by rotating the large wheel. A metronome is also required for this demonstration. The connections have been taken out from the disc-one from its centre A and another from a point B on the boundary of

[3]An improvised U-magnet can be made out of 2 bar magnets as described in Appendex 9 A very good C-shaped electromagnet can also be improvised out of a burnt out choke of a fluorescent tube, if you have one, as described in Appendix 10.

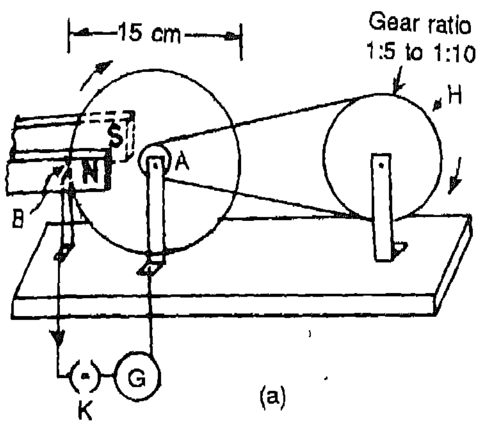


Fig. 4.6 a. *As the disc rotates, induced emf is produced in it along the radius AB*

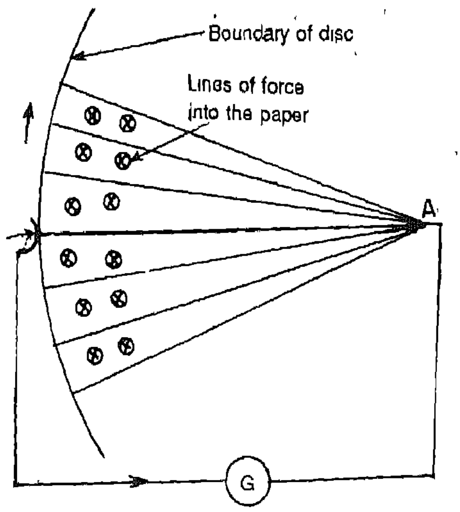


Fig. 4.6(b)

the disc between the poles of the magnet as shown. Gear ratio can be made around 1:5 to 1:10, that is for one rotation of wheel there are five to ten rotations of the disc.

Select the frequency of the metronome to 20 beats per minute and give one rotation to the wheel for every beat. In this manner you make 200 rotations of the disc per minute. By increasing the frequency of metronome and rotations of the large wheel in synchronization, you can easily increase the number of rotations of the disc upto 1500 per minute with a little practice.

Now connect the disc to a sensitive galvanometer and rotate the disc at the rate of 200 rotations per minute. You will observe some deflection in the galvanometer, note it. Increase the speed of rotation of the disc to 300 rotation per minute and note the deflection. Repeat the experiment for several values of the speed of rotation of the disc. Reason for this induced emf is as follows.

The disc can be treated as a combination of a large number of radial bars (like spokes of the wheel of a bike) which cut across the magnetic lines of force (Fig. 4.6b). The emf induced in the spoke which is along the radius AB, causes a current to flow in it and the galvanometer, which is measured by the deflection of the galvanometer You will observe that (i) the deflection is obtained only when the disc is rotating, (ii) higher the number of rotations of the disc per minute, the higher is the deflection in the galvanometer, and (iii) direction of induced emf in the 'spokes' is according to Fleming's right hand rule, illustrated in Fig. 4.6c.

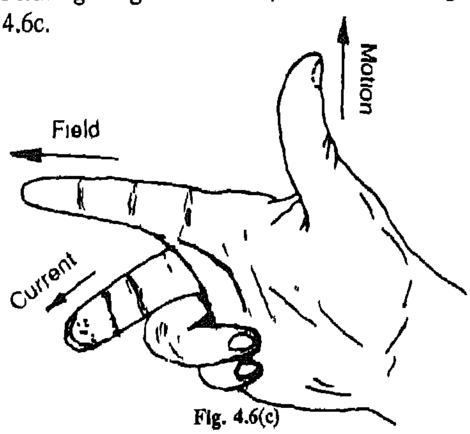


Fig. 4.6(c)

If either you have good practice of rotating the disc with constant speed or if the disc is driven by an electric motor whose speed can be changed at will, you can demonstrate that induced emf in proportional to speed of rotation of the disc.

4.7 (Acitivity) To illustrate that the induced emf in a conductor cutting across lines of force is proportional to the rate of cutting across the magnetic flux (Faraday's law).

The apparatus required for this activity is shown in Fig.4.7. It consists of a half rectangle shaped

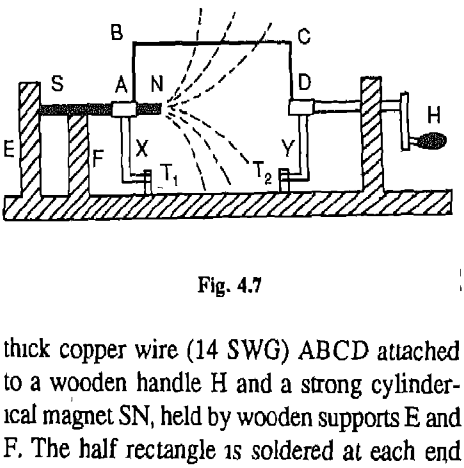


Fig. 4.7

thick copper wire (14 SWG) ABCD attached to a wooden handle H and a strong cylinderical magnet SN, held by wooden supports E and F. The half rectangle is soldered at each end to a circular collar of thick copper sheet. Through the collar at end A passes the north pole of the magnet. The other collar is attached to the handle, H. The brass strips X and Y make contact with the collars and their other ends are joined with the terminals T_1 and T_2. The contact friction is minimised by oiling them. A sensitive galvanometer and a metronome are also required.

Connect the galvanometer to terminals T_1 and T_2. Set the metronome to any desired beat frequency, say 30 beats per minute. Using the handle H rotate ABCD so that one rotation is completed for every beat

As the wire cuts across the lines of force, a continuous d.c. emf is induced. With some practice, uniform speed of rotation can be achieved as observed by a steady deflection of the galvanometer Note the deflection, θ_1. Now rotate ABCD in the opposite direction at the same rate in a similar manner and note the deflection θ_2 in opposite direction. Find the mean deflection, θ.

Increase the frequency of the metronome and repeat the experiment for different speeds of rotation. Higher the speed of rotation, the greater is the induced emf. The rate of cutting the magnetic flux is proportional to f, the beat frequency of the metronome, which is also the frequency of rotation of the wire ABCD. The induced emf is proportional to θ. Thus a straight line graph between f and θ, passing through the origin, demonstrates the Faraday's law of induction, viz. induced emf is proportional to rate of cutting the magnetic flux.

Note: This activity can also be done by using the apparatus of demonstration experiment 4 6, shown in Fig. 4.6. In fact that demonstration can be done by an ordinary galvanometer having a sensitivity of about 1 m V per scale division. Activity 4.7 on the other hand, requires a hundred times more sensitive galvanometer (a suspended coil galvanometer). Advantage of activity 4.7 is that it is conceptually simpler. You see a wire cutting across lines of force and showing an induced emf.

TOPIC II· LENZ'S LAW FOR THE DIRECTION OF INDUCED emf.

4.8 (Demonstration): To demonstrate that the induced emf is such that it opposes the cause of its production.

Make a coil (7 to 8 cm diameter) of 5 to 10 turns, using a thick (3 or 4 mm diameter) copper

or aluminium wire. Twist at least 3 cm to 4 cm length of each end of the wire together to make its handle, which ensures also the good electrical contact between the two ends. The simplest way to make it is to wrap the wire on a glass tumbler. After twisting the ends together, it can be slipped out towards the thinner end of the tumbler (Fig. 4.8a)

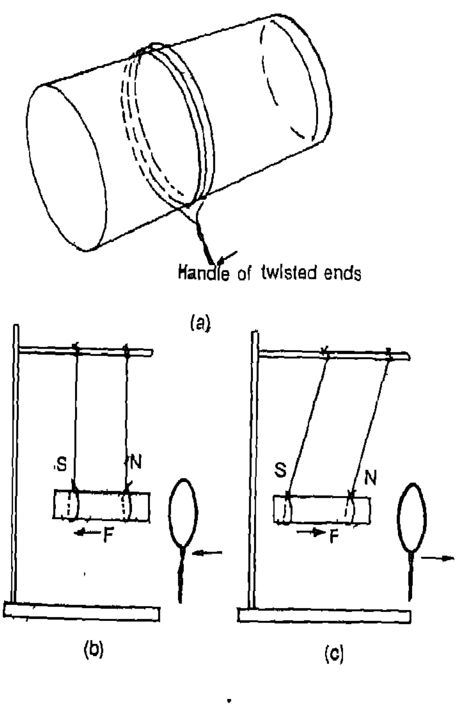


Fig. 4.8 (a, b, c)

Suspend a strong bar magnet from a laboratory stand horizontally by two threads as shown in Fig. 4.8a. Hold the coil perpendicular to the magnetic exis of the magnet Quickly bring it near the magnet (but don't touch it) you will observe that the magnet is pushed back a little (Fig 4 8b). As the magnet starts moving back to the equilibrium position, quickly move the coil away and you will observe that a pull acts on the magnet (Fig 4.8c) In this manner, without touching the magnet, quite a large swing can be built up.

—Inference, clearly, is that when mutual distance between coil and magnet is decreasing, induced current in coil is in such direction that the repel, i.e. it opposes the decrease of distance. When their mutual distance is increasing, there is force of attraction which, again, opposes this increases of mutual distance. This proves the Lenz's law which states that the induced emf is in a direction so as to oppose the cause of its production.

Even in demonstration 4 1 above, if you perform the experiment carefully you can feel the force of attraction and repulsion of magnet by the coil, during the period the magnet is motion

Notes· 1 For this demonstration it is essential to use thick wire. Its low resistance ensures the production of a large current by the small induced emf, thereby developing a substantial force between the magnet and the coil.

2. In each of the experiment 4.3, 4.4, 4.6 and 4.7 above, a conductor moves in a magnetic field and an induced emf is produced in the conductor, Find out the direction of induced current, with the help of the polarity marked on galvanometer for deflection of its needle towards right hand side. Then with the help of Fleming's left hand rule, find out in each experiment the direction of force experienced by the concerned conductor moving in the magnetic field. You will find that this force opposes the motion of the conductor.

3. In each of the experiments 4.1, 4 2 and 4.5 above the flux of magnetic field through a stationary coil changes. Thus an induced emf is produced in the coil. Find out the direction of

induced current, with the help of polarity marked on galvanometer for deflection of its needle towards right hand side. Then with the help of cork screw rule find out the direction of magnetic field produced by this current at the centre of the coil You will find that the magnetic field of induced current opposes the change of flux through the coil and tries to keep it constant.

TOPIC III . EDDY CURRENTS

4.9 (Demonstration) To demonstrate the production of eddy currents in a conductor placed in a varying magnetic field (jumping ring).

The apparatus for this demonstration is a large bar electromagnet and is commercially available. It consists of a coil P, having a large number of turns of thick copper wire and a long I-core of soft iron core, AB, as shown in Fig 4.9. An Aluminium ring, S, rests on the coil.

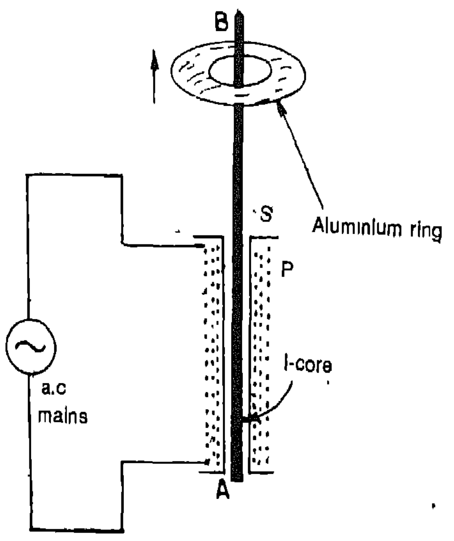


Fig. 4.9

Alternatively, a coil (inner diameter 2 or 3 cm) can he made using thick enamelled copper wire with a t least about 1000 turns. A long soft iron bar (diameter 2 or 3 cm) can be used as its core and the aluminium ring rests on this coil

When the a.c. current is switched on, the aluminium ring is thrown up. The cause of this throw is eddy currents, which are the currents induced within any conductor across which the magnetic flux is changing. These currents cause a magnetic force on the ring, whose direction can be easily found The current passing in the coil is a.c., i e it changes its direction after every 1/100 second. During the interval of 1/100 second when it is in one direction, first it gradually increases and then gradually decreases to zero Thus there is continuous change of flux passing through the ring. The ring can be considered as the secondary coil of one loop, in the transformer consisting of this ring and the coil P. The induced current in the ring is also an a.c., which is always opposite to that in a coil P. Thus at any instant, the coil P and the ring both behave like magnets with their similar poles facing each other, though the polarity of each is continually changing which cause a repulsion between them (Fig. 4.10).

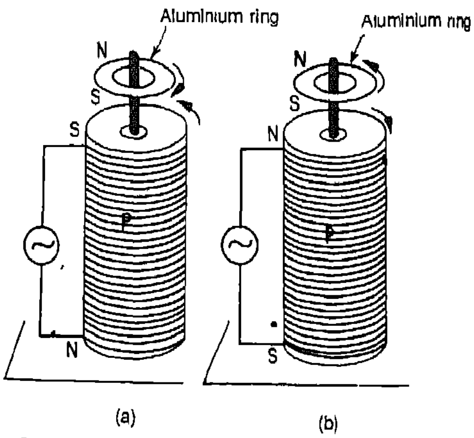


Fig. 4.10 *Whatever the direction of a.c in coil P at an instant, the direction of induced current in the ring is opposite to it. Force of repulsion between the two currents throws off the ring.*

4.10 (Demonstration): To demonstrate the solwing down and repulsion of a trolley due to eddy currents.

The apparatus required for it includes the electromagnet used in demonstration 4.9 and a small metallic toy trolley, Fig. 4 11. Switch on the a.c.

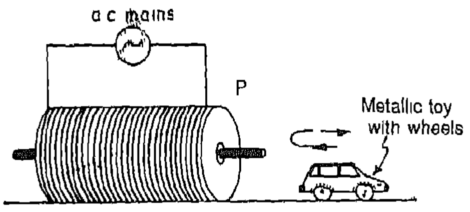


Fig. 4.11 *Eddy currents in the metal body of toy car repel the a c in coil P Thus the car slows down and then moves back.*

current and push the trolley towards the core of the electromagnet by a stroke of your finger. You will observe that as the trolley moves towards the electro-magnet, is slows down because of th reasons given above in the demonstration 4.9 and, then, moves back, if friction of its wheels is quite low. The demonstration is best done with a toy of aluminium, which is lighter then iron and is a much better conductor than iron (see table of resistivities of metals in data section).

4.11 (Activity): To construct a model of an automobile speedometer based on eddy currents.

Automobile speedometers depend on eddy currents. One of the wheels of the automobile is coupled by a flexible shaft to a permanent magnet which is kept beneath an aluminium cup. When the automobile is moving the magnet rotates. Eddy currents induced in the cup produce a rorque causing the rotation of the cup in proportion to the speed of rotation of the magnet.

An improvised speedometer for laboratory demonstration can be constructed as follows Cut a square piece (10 cm x 10 cm) out of a thin aluminium sheet (SWG 26 or 28). Mark its centre C and bend its corners up as shown in Fig. 4.12(a) so that its C.G. is a little above C. Hang the aluminium plate upside down using a rubber string or thin metal wire so that is is horizontal, Fig. 4.12(b). Now its C.G. is a little

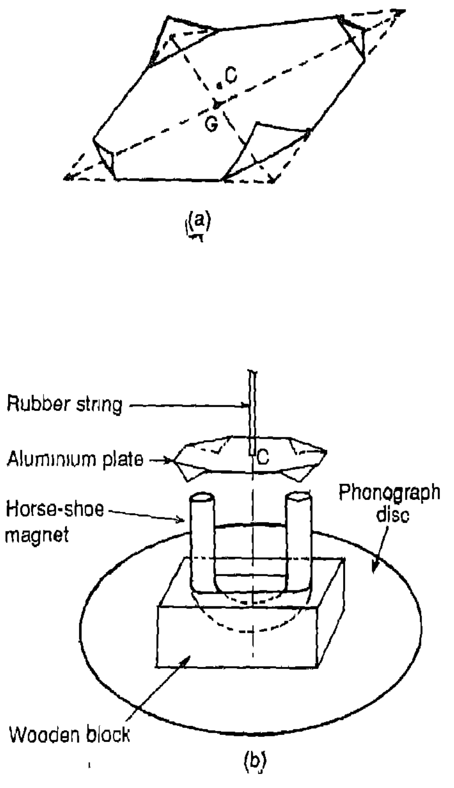


Fig 4.12 a, b. *Deflection of aluminium plate is proportional to speed of rotation of the magnet.*

below its centre C and it is in a stable equilibrium. Thus if it is given a twist, it oscillates in horizontal plane like a torsion pendulum, due to elasticity of rubber string/metal wire.

The horse-shoe magnet is held below the aluminium plate with its poles upwards. The magnet is held vertical in a wooden block placed at the centre of a phonograph disc The magnet and aluminium plate are so positioned that axis of rotation of phonograph, is the axis of symmetry of magnet and also is the axis of horizontal oscillations of the plate

As the phonograph disc and the magnet rotate, the aluminium plate deflects from its equilibrium position. The faster the speed of rotation of phonograph disc, the greater the torque acting on the aluminium plate and the greater is its deflection from its equilibrium position.

TOPIC IV· MUTUAL INDUCTION

4.12 (Demonstration): To demonstrate that an induced emf is produced in a coil placed near another coil carrying changing current.

(a) You have seen in demonstration 4.2 that when current is passed or stopped in a coil P, induced emf is produced in a coil S placed near it in such a manner that magnetic field lines produced by P pass through S. After this demonstration, interchange galvnometer with battery and key without changing the position of the two coils. Thus you switch on and switch off current S and observe induced current produced in P. Thus you observe that varying current (increasing or decreasing) in any of the coils induces a current in the other This phenomenon is called *mutual induction.*

(b) Next, pass a current in P by a 6 volt a.c. source, with help of a rheostat adjust the current to about 2A or 3A and note the current by an a.c. ammeter (Fig. 4.13). In the coil S, instead of galvanometer connect an a.c. voltmeter[4]. Thus note the a.c. voltage induced in S.

Now, without altering the positionsof the two coils, connect the 6 volt a.c. source rheostat and a.c. ammetr to coil S. Pass the same a.c. current in coil s was passed in P, in first part of

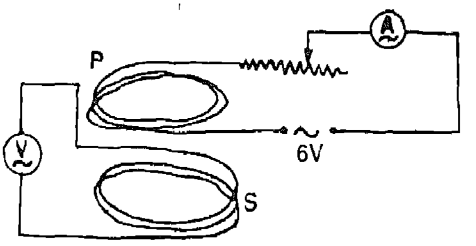


Fig 4.13 *Coils P and S have a mutual inductance. Same alternating current in P or S induces same alternating voltage in the other coil*

experiment. Connect the a c voltmeter in P and note the a.c. voltage induced in it You find that this induced voltage is same as was induced in coil S in the first part of the experiment.

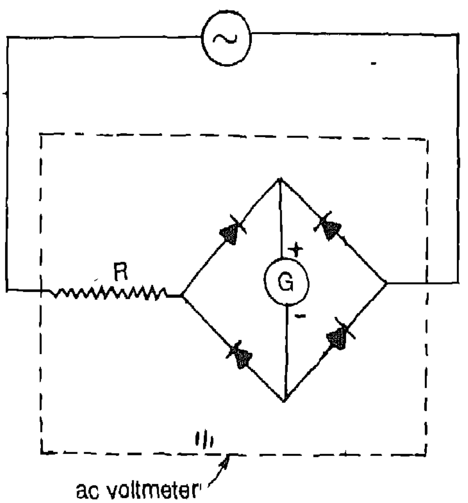


Fig. 4 14 *A d.c galvanometer with a resistance in series with it functions as an a c voltmete with the help of a bridge rectifier.*

[4] A d c galvanometer is connected to an a c source, its needle only about he zero-mark. If it is connected thorugh a bridge rectifier (Fig 4.14), then direction of current in galvanometer does not change when the main current changes direction Thus the galvanometer registers the alternating current too Figure 4.14 shows how by connecting an appropriate series resistance, it can be converted into an a c voltmeter An a c ammeter can also be similarly made.

Notes: 1. Basically the change of flux of magnetic field through a coil induces an emf in it, which in its turn, causes a current to flow Magnitude of the current is governed by Ohm's law. Thus, if the circuit of the coil is not a closed circuit, there is no current flow But, electrostatic potential difference exists (Fig. 4 15a) between the two free ends of the coil in this case, as long as the flux through coil S is changing

2. When a straight conductor cuts across lines of force of a magnetic field (Fig. 4.15b), the conductor can be considered to be part of an incomplete circuit (shown by broken line) The flux through this circuit changes due to motion of the conductor. The flux through this circuit changes due to motion of the conductor. Thus there is no current flow in the circuit, but a potential difference develops across the ends of the conductor. There is a redistribution of electrons in it, identical to that which occurs by the vicinity of a charged rod (Fig. 4.15c) Direction of induced emf in the conductor can be determined either (i) by Lenz's law considering the imaginary incomplete circuit (Fig. 4.15b), or (ii) by the Fleming's right hand rule.

4.13 (Demonstration): To demonstrate the effect on mutual induction by the introduction of an iron core linking the two coils.

For this experiment you need the coil (of 1000 turns) and long straight core of soft iron used in experiment 4.9, and shown in Fig. 4 9 You, also need the small coil used in experiment 4.5 (of 40 SWG copper wire, 100 turns, diameter about 5 cm)

Support the two coils horizontally on the table at some distance from each other. Connect the smaller one to a galvanometer and the larger one to an accumuxlator, through a tapping key (Fig. 4.16a). When the current is passed or stopped in the larger coil, small deflections are observed in the galvanometer, indicating small induced emf's in the smaller coil, in both cases.

Now without disturbing the positions of the two coils, place the soft iron core such that it extends from one coil to the other (Fig. 4 16b). Again, observe the deflection in the galvanometer on passing or stopping the current in the larger coil. This time the deflection are much

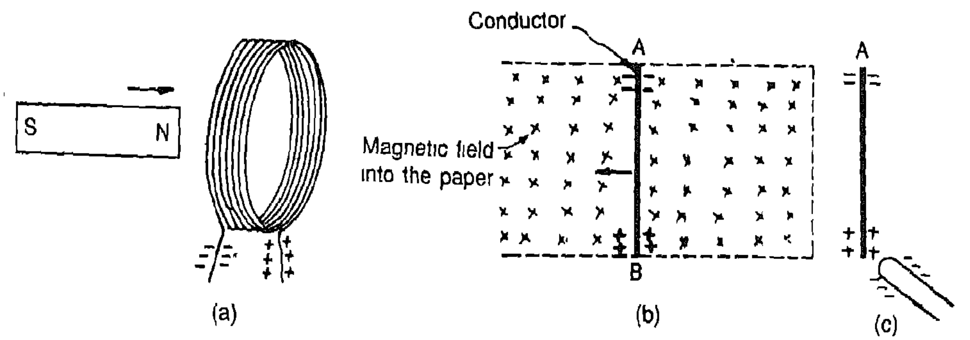


Fig. 4.15 (a, b, c)

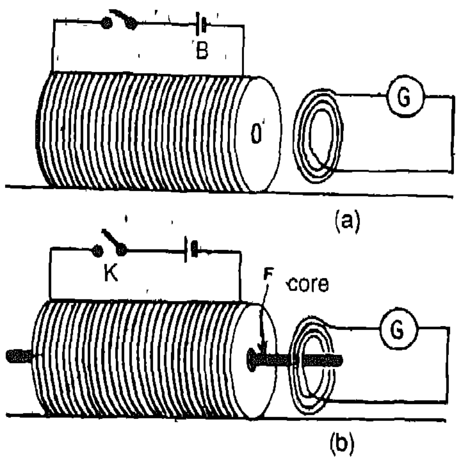


Fig. 4.16 a, b. *Introduction of an iron core linking the two coils enormously increases the mutual induction*

larger. The reason is that magnetic lines of force tend to concentrate in the iron core. Thus much larger flux produced by larger coil passes through the smaller one. Also the iron core gets magnetised by induction and produces some extra magnetic flux, which also passes through both the coils.

Next, use the 6 volt a.c source, rheostat and a.c. ammeter of experiment 4.12 (b) to pass a measured alternating current in the larger coil. Then measure the alternating voltage induced in the smaller coil (i) without the iron core and (ii) with the iron core, using an a.c. voltmeter. How do the induced voltages in the two cases compare with each other?

4.14 (Demonstration): (a) To demonstrate the principle of transformer by winding primary and secondary on a steel rod; and (b) to demonstrate removal of eddy currents by using laminated core.

(a) The transformer is an important application of mutual induction. Depending upon the ratio of turns in the two coils, a transformer can step-down or step-up a c voltage, It can be demonstrated as follows.

Take a soft iron rod of 15 cm length and 1.3 cm diameter Wrap thick paper on it Wind a coil P of enamelled coper wire (22 SWG or 20 SWG)with 200 turns. Wind another coil S of thick enamelled copper wire (18 SWG or 16 SWG)P with 50 turns as shown in Fig. 4 17 Both coils

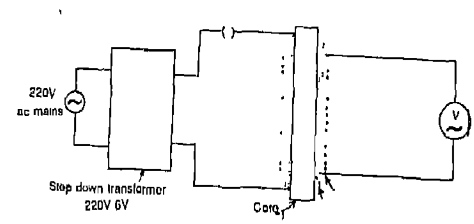


Fig 4.17 *A simple transformer made by winding two coils on an I-shaped iron core.*

are wound over same length of the rod, so that almost the entire flux produced by current in one is linked to the other. Connect the coil P with 6 V a c. supply (obtained froma stepdown transformer). Connect the coil S with an a.c. voltmeter (0-10V). Connect an identical a.c. voltmeter across coil P also. Switch on the current in P and note the voltage V_p and V_S across the two coils. Find the ratio of V_p to V_S. You find that this ratio is equal to the ratio of the number of turns in the coil P to that in the coil S, i.e.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

The coil P (on which a.c. voltage is applied) is called the *primary* and coil S (in which a.c is induced) the *secondary*. Since coil is placed very close to the coil P (they are not connected to each other, rather they are separated by insulating enamel), the power in the primary is transferred into the secondary through mutual

induction. As is clear from the above equation, by appropriate choice of the turn ratio, i.e obtain a higher voltage or lower voltage in S compared to that in P.

It shold be noted that a steady d.c. voltage cannot be stepped up or stepped down by a transformer, because a steady d.c. current does not produce changing magnetic flux and, therefore, cannot produce induced voltage.

(b) In the above demonstration, connect P to 6 V a.c. for some time continuously and feel the hotness of the core and coil by hand. You will find that the core soon gets hot, while the windings of copper wire are comparatively cooler. Switch off when it is rather too hot to touch, otherwise the enamel coating of copper wire may born out.

The core gets hot due to eddy currents induced in it (resistive heating). Consider the core to be composed of large number of cylinderical shells and consider any one of them (Fig. 4.18). The changing magnetic flux passing through this shell induces current in it, as in a coil. Such induced currents are produced in every shell of which the core is composed.

Now instead of a solid iron rod you take laminated core consisting of thin soft iron wires insulated from each other by an enamel coat and pressed together. Repeat the above demonstration using this core. You find that the core made of wires does get hot, but much more slowly. Insulating enamel amongst the soft iron wires reduces eddy currents considerably, as the current cannot flow from one wire to another. However, there are some eddy currents within each wire too. It may be mentioned here that this kind of core also becomes useless for higher frequencies.

4.15 (Activity): To demonstrate the principle of a dynamo by means of a bicycle lighting set.

The bicycle lighting set (or bicycle dynamo) consists of a 4-pole rotor magnet placed between the ends of C-shaped laminated core of a coil conected to a bulb (actually in the shape of 4 C's put together, Fig. 4 19). One end of the axle

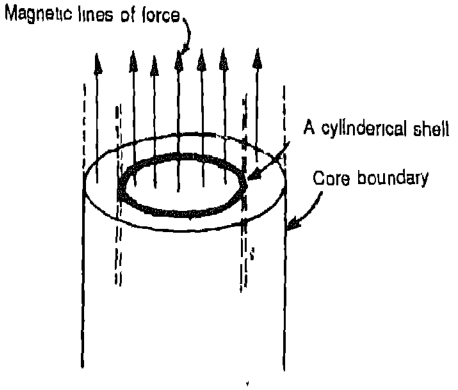


Fig. 4.18 *Changing magnetic flux within the core produces induced emf around any cylinderical shell within the core*

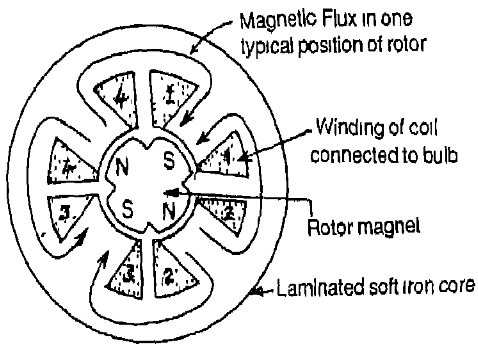


Fig. 4.19 *Working of bicycle dynamo.*

of rotor magnet is connected to a driver which is brought in contact with one of the wheels of the bicycle, so as to rotate the rotor magnet. When the magnet rotates, the induced emf is produced in the coil resulting in the glow of the bulb You can easily open up a bicycle dynamo and show above mentioned features in it, with the help of simple hand tools. It is evident from Fig 4.19 that in one revolution of the rotor magnet, magnetic flux through laminated core changes direction 4 times and so does the a.c. induced in the coil wound on it.

An improvised laboratory setup to demonstrate the principle of a dynamo can be made easily as follows, if you have a condemned fluorescent tube choke. Convert it into a C-shaped electromagnet, as described in appendix 10.

The magnet used as the rotor is made out of two commercially available ceramic toy magnets, each of dimentions 3.6 cm x 1.2 cm x 0 35 cm and having magnetic polarisation along the length of the bar, Fig. 4.20(a).Cut the spoke of a bicycle wheel and place it between the two magnets to form an axle. The gap between the magnets is filled with paper packing. The magnets, paper packing and the axle are glued together by means of apoxy glue to form a rotor as shown in Fig. 4.20(b). It is remagnetised usin a powerful electromagnet so that it develops widthwise polarity as shown in Fig. 4.20(b). However, if laterally magnetised toy magnets

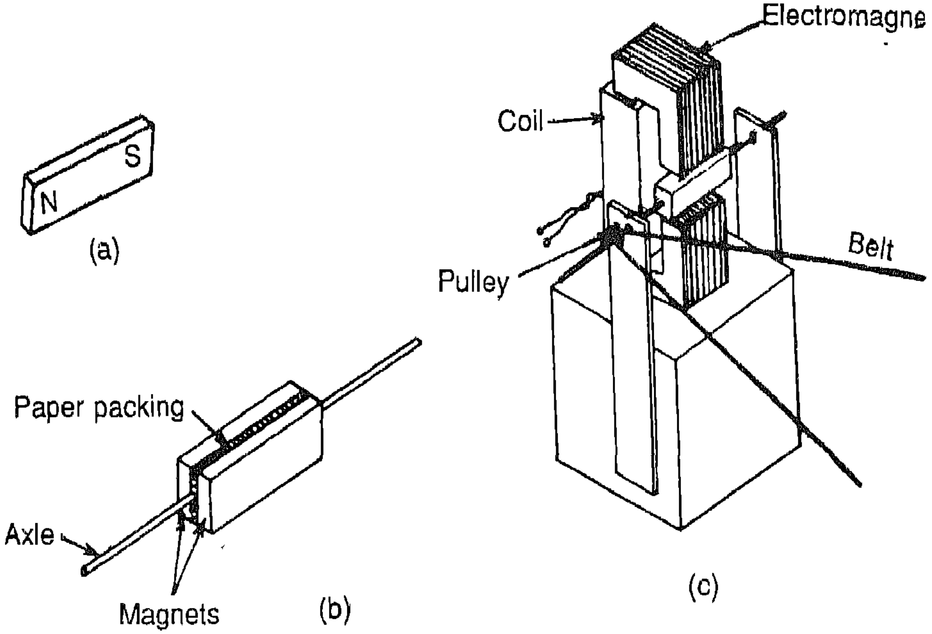


Fig. 4.20 a, b, c, d, e. *Making an improvised generator*

[5]Ref SOMNATH DATTA, "Low Cost Electromagnetic Induction Kits out of the Condemned Chokes of a Fluorescent Tube", A brochure published by Regional College of Education, Mysore-570006, (1986)

are available then it is not necessary to remagnetise them.

Clamp the coil on a wooden block. Mount the motor on two thin aluminium plates screwed

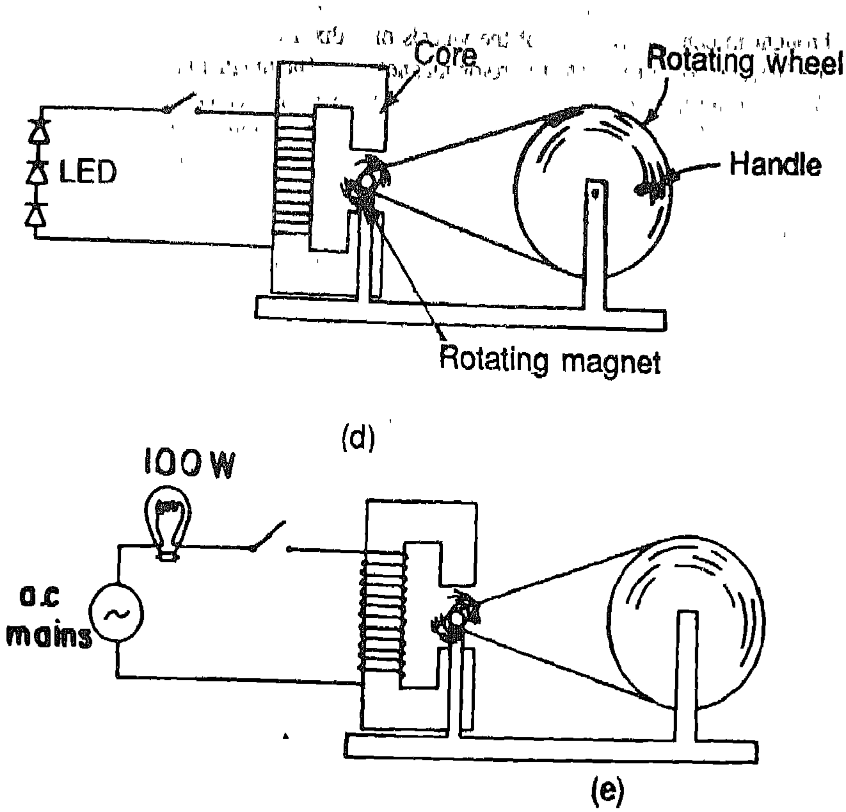


Fig. 4.20 (d, e)

on to the sides of the wooden block as shown in Fig. 4.20(c) so that it can be rotated between the gap of the core A small pulley is attachedto the axle which is coupled to a wooden wheel of about 15 cm diameter by means of a thread. The two ends of the coil wound on the electromagnet are connected to an LED. The whole arrangement is shown in Fig. 4.20(d)

By rotating the wooden wheel, the rotar is roated which results in the production of induced emf in the coil and glowing the LED. The higher is the speed of rotation, the larger is the intensity of glow. Instead of one LED, two or three LED's can be used in series

The same device can function as a c. motor as well Connect the electromagnet to 220V, 50Hz mains through a 100W bulb, so that voltage across its terminals is only 60V (Fig 4 20e). Rotate the wooden wheel by hand and leave. If the rotor has picked up a speed of 50 revolutions per second, it will continue rotating due to forces applied on it by the electromagnet

4.16 (Demonstration) To demonstrate the production of a large induced emf by an induction coil.

Demonstrate the working of an induction coil. With the help of a 6 volt lead accumulator, it can produce such a high voltage as causes a

spark to jump across an air gap of 4 cm or 5 cm. The apparatus must be used with caution and if this voltage happens to be applied to any one's body, substantial damage can be caused to the body.

Following essential features may be demonstrated and explanied, which helpin producing a high induced emf

(i) The secondary coil consists of a large number of turns of a thin wire Since all the turns can be considered to be connected in series, the emf induced in each turn adds up to makeahigh induced emf. For this very reason the secondary coil S is divided into sections. Fig. 4.21 shows a sectional view of the secon-

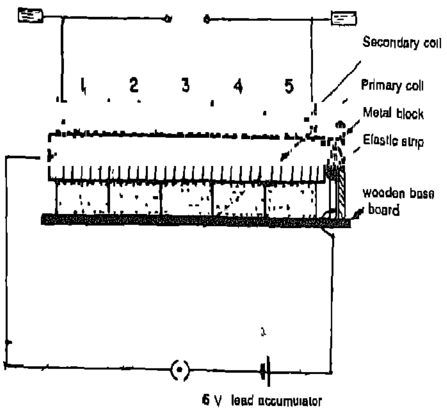


Fig. 4.21. *The inside of an induction coil*

dary coil with five sections separated from each other by rings of insulating material. Whereas the turns of wire within one sections are in series, the various sections are also connected in series. Thus the section 8 and section 1, between which there is a large potential difference, are far apart and there is no risk of short circuiting within the coil.

(ii) Primary coil consists of a few turns of a thick wire which can draw a large current. In the core too, there are a large number of straight thin iron rods, coated with insulated enamel. Thus a large magnetic flux created by primary is linked with secondary coil.

(iii) Primary coil is connected to the accumulator through a buzzer i.e. an elastic strip with an iron hammer at its free end. As the primary coil current increses beyond a certain value, iron core attracts the hammer and the current drops to zero. Thereafter, force of attraction by the iron core ceases, hammer goes back to original position, makes contact with metal block and again the primary current builds up. Frequncy of the buzzer is quite high and thus primary current stops and stars may times each second. Thus rapid changes in manetic flux are caused and a high induced emf is produced in the secondary coil

TOPIC V. BEHAVIOUR OF AN R-C CIRCUIT WHEN A D C VOLTAGE IS APPLIED

4.17 (Demonstrtion): To demonstrate that the charging or discharging of a capacitor is not instantaneous but takes time, using a measuring electroscope.

Take a capacictor of 2μF (500 V rating) and a resistor of 5 M Ω. Connect them with a 300 volt d.c. voltage source and a sensitive measuring electroscope, as shown in Fig 4 22 Close

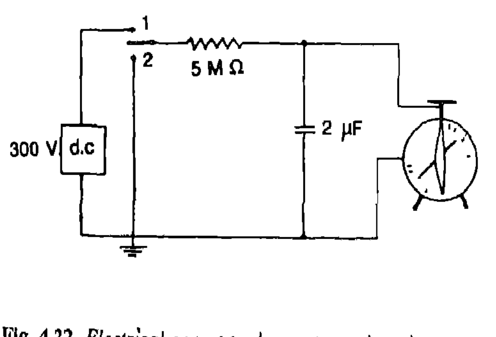


Fig. 4.22 *Electrical circuit to demonstrate that charging or discharging of a capacitor is not instantaneous*

the two-way switch in position, 1 The capacitor will be charged to the voltage V(which is 3000V). However, the pointer of electroscope does not reach the maximum deflecion instantaneously. It takes almost 30 seconds to reach near the deflction, which represents the potential difference of 300 volt.

Next, close the two-way switch in position 2. The capacitor is now discharged through the 5 MΩ resistor. Again, observe that the pointer of electroscope does not reach zero deflection instantaneously It again takes almost 30 seconds to reach near the zero deflection position.

Note: If you have a very high resistance of 500 GΩ, you can use it to demonstrate that a simple spherical conductor of 20 cm diameter on insulated stand also takes time to be charged by the 300 volt d.c. source. Use the same circuit as shown in Fig. 4.22 replacing the condenser by the conductor, with its stand placed on a metal sheet. This metal sheet serves as the earth connection on which is also placed the electroscope. Surface of the stand of the spherical conductor and of insulation on the electroscope must be quite clean, lest their surface leakage resistance may be of same order or less than 500 GΩ.

4.18 (Experiment): To study how the p.d. across a capacitor varies with time during charging and discharging of the capacitor.

Apparatus: An electrolytic capacitor of 220 Ω carbon resistor, a d c. power supply (0 to 24V) a voltmeter (0-25V), two way switch, and a timer (metronome) The voltmeter should be a multimeter of at least 20,000Ω/V sensitivity, set at 0-25 or 0-30V range.

Theory: If a capacitor of capacitance C is connected to a d.c. voltage V_0 through a resistance R_1 voltage V across the capacitor at time t is. $V = V_0$ (1-$e^{t/RC}$) Again if the capacitor charged to voltage V_0, is discharged voltage, V, across it at time t is $V=V_0e^{t/RC}$ Thus in case of charging the difference V_0-V decreases exponentially reducing by a factor of 2.72 in a time interval equal RC. During discharging the voltage V itself behaves similarly The time interval RC is known as the *time constant* of th circuit.

Method: Connect the circuit as shown in Fig. 4.23(a) with R=10 K and C=2200 μF. To

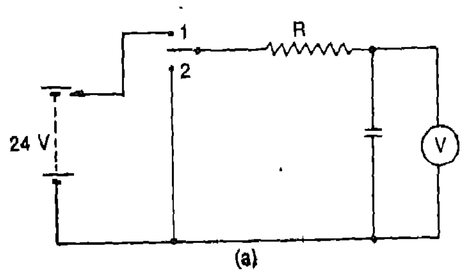


Fig. 4.23 a, b, c

avoid unwanted discharge through the voltmeter, use higher voltages (20 to 24V) so that voltmeter has high resistance (more than

time t (s)	Voltage during charging, V (volt) 1	2	3	Mean	Voltage during discharging, V (Volt) 1	2	3	Mean
5								
10								
—								
—								

400KΩ. Also use such a two-way switch in which the connecting rod jumps from position 1 to 2 or back very fast. The common stair case switch will serve well.

Adjust the metronome to give 'tick' sound (or beat) every 5 seconds. Bring switch to position 1 and switch on the metronome simultaneously. Note the value of V in the voltmeter at every 'tick' till you get a steady value of V Record the readings as described in the table given under 'observations".

Now bring 2-way switch to position 2 and switch on the metronome simultaneously. Note the value of V every 'tick' still V is nearly zero. Record the observations in the above table Both the sets of observations are reproducible. Therefore, you can bring the switch alternately to position 1 & 2 several times, note each set of observations thrice and find the mean value of voltage at each value of time.

Plot two graphs between V and t, Fig 4.23(b) and Fig 4.23(c0, for charging and disc[illegible]

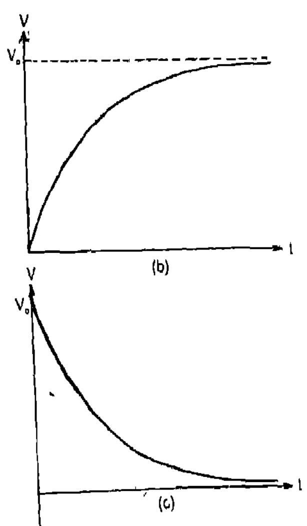


Fig. 4.23

of the capacitor. The graphs show exponential rise and fall of the voltages.

Find from graph of Fig. 4.3(b) the time interval in which value of (V_0-V) reduces by a factor of 2.72. Similarly, from graph of Fig 4.23(c), find the time interval in which the value of V reduces by a factor of 2.72. Are these two time constants same within experimental error?

Calculate the time constant by multiplying the values of R and C mentioned by the manufacturers and compare the measured value of time constant with the calculated one

Observations:

Capacitance of condenser, C = __________ μF
Resistance in series, R = ____________ ohm
Voltage applied, V_0 = __________ volt.
Time constant, RC (using quoted values of R & C) =
Time constant from graph of charging =
Time constant from graph of discharging =
Note: If the resistance of voltmeter is comparable to resistance R, then measured value of time constant during charging may be too large and during discharging may be too small Why?

4.19 (Experiment): To study how the d.c. current in an R-C circuit varies with time during charging and discharging of the capacitor.

Apparatus: An electrolytic capacitor of 200 μF (30 volt rating), a 10 KΩ resistor, a d.c. power supply milliammeter of range 2.5 mA on either side, a two way switch and a metronome

Theory Consider the circuit given in Fig. 4.24(a) When the 2-way switch is in position 1, the current I following through the R-C circuit during charging is

$$I = I_0 e^{-t/RC}$$

Where $I_0=V_0e^{-t/RC}$

where $I_0=V_0/R$. The current flowing through the circuit during discharging (switch in position 2) is given as

$I = I_0 e^{-t/RC}$

Method: Connect the circuit given in Fig 4 24(a) with R & C same as above. Metronome

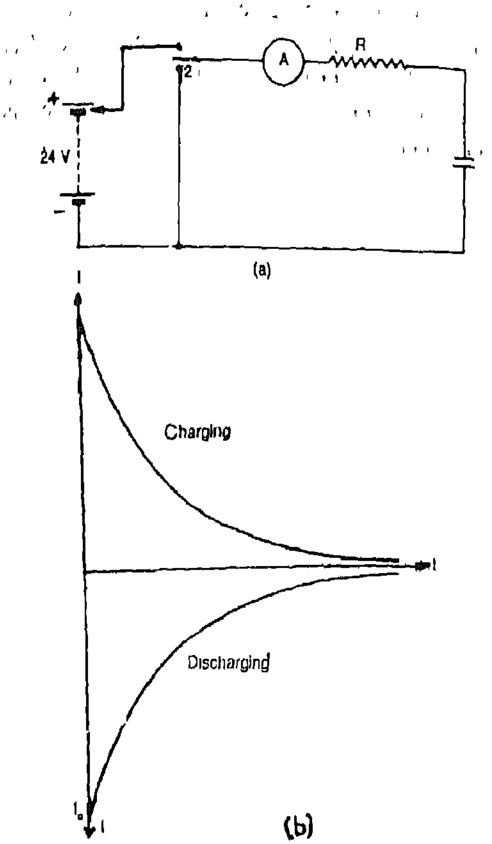


Fig. 4.24 a, b.

is adjusted to give 'tick' sound every 5 seconds. Bring 2-way switch to position 1, and switch on the metronome simultaneously. Note the value of I at every 'tick' till you get almost zero current. Record the observations in the table given under observations.

Now bring the 2-way switch to position 2 and switch on the metronome simultaneously. Note the value of I at every 'tick', till it is almost zero. Record these observation too in the table of observations. Repeat charging as well as discharging, note each set of observations thrice and find the mean values of current.

Plot a graph between I and t for charging and discharging as shown in Fig. 4 24(b) The graph shows the expenial fall of the current

From each graph find the time interval in which the curent reduces by a factor of 2.72. Are the two time constants same, within experimental error ? Compare the measured value of time constant with the calculated one

Observations:

Capacitance of condenser, C = __________

Resistance in series, R, = __________

Time constant RC (using quoted values of R & C) =

Time constant from graph of charging =

Time constant from graph of discharging =

TOPIC VI: BEHAVIOUR OF AN LR CIRCUIT WHEN A D C VOLTAGE IS APPLIED

4.20 (Demonstration): Demonstrate that the current through an inductor does not reach the steady value instantaneously when a d.c. voltage is applied, but takes some time.

Note . This is an expensive experiment requir-

Time, t (s)	*Current I during charging* (mA)				*Current, I during discharging* (mA)			
	1	2	3	Mean	1	2	3	Mean
0								
5								
10								
—								
—								

ing costly choke, which you may have to make with the help of a local craftsman (transformer maker).

An inductor can be made having a self inductance as big as about 2500 henry, in which resistance of windings of copper wire is as low as about 250 ohm. It is much bigger and costlier than the common fluoroscent tube choke, which has a self inductance of about 1 henry. It uses a core made of an iron-nicked alloy of very high permeability (see table 10 in data section). One design for such an inductor is suggested in appendix 11.

Connect the inductor L in series with a 1.5 V dry cell through a 2-way switch S (staircase switch) and a millammeter (0-10 mA) (Fig. 4.25). Connecting rod of the 2-way switch

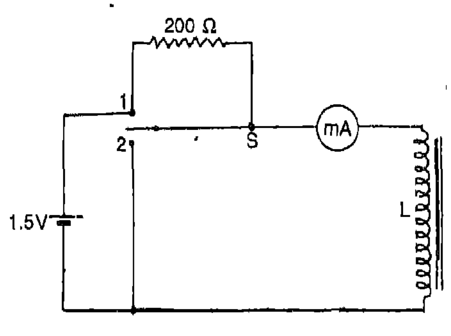


Fig. 4.25 *Electrical Circuit to demonstrate that current in an inductor does not reach its steady value instantaneously.*

jumps from pole 1 to the pole 2, or vice versa, very fast. In position 2 of the switch the terminals of L are short-circuited while a small current of 7.5 mA drains from the cell through the 200 ohm resistor. In position 1 of the switch, the e.m.f. of 1.5 V is applied to the inductor, L and the 200 ohm resistor is short-circuited.

Set a metronome to give ticks at intervals of 1 seconds. At a beat of the metronome, turn the switch to position 1, thus applying the 1.5 volt emf to the inductor. You observe that it takes quite some time for current to reach the steady value, which is about 6mA. Keep counting the beats and thus find out the time in which the needle of ammeter reaches close enough to its final position.

Next turn the switch to position 2, thus short circuiting the inductor, L at a beat of the metronome. Again you observe that it takes quite some time for current to fall to zero-value. Keep counting the beats and thus find out the time in which the needle of ammeter reaches close enough to zero-position. Is this time same as in case of the increasing current?

Note: One may ask what is the function of the 200Ω resistor connected at the pole 1 of the switch. During the fraction of a second when switch is flying from pole 1 to 2, it allows a low resistance of circuit to be maintained and current through the inductor L does not change. In the absence of this resistance, the current through L will abruptly come down to zero with a spark during the flight of the switch from pole 1 to pole 2, as the circuit would be open.

4.21 (Experiment): To study how the current through an inductor varies with time when a d.c. voltage is applied to it or when it is reduced to zero.

Apparatus: An iron cored inductor of large inductance and low resistance, an ammeter (0 to 10 mA) a dry cell, a two way switch, a metronome.

Procedure: Use the same inductor and same circuit as for experiment 4.20 shown in Fig. 4.25. Set the metronome to give beats at a suitable interval (3 or 4 or 5 seconds). At a beat of the metronome, turn the 2-way switch to position 1, thus applying the 1.5 volt emf to the inductor. At each subsequent beat, note and speak out current in the circuit and let a colleague record it. The interval between beats

Observations:

time t (s)	Current I during rising (mA) 1	2	3	4	Mean1	Current, I during decaying (mA) 2	3	4	Mean

should be sufficient for you to do this task, but small enough to give you 5 or 6 readings at least, untill the needle of ammeter reaches close to its final position.

Next, turn the 2-way switch to position 2, thus short circuting the inductor, at a beat of the metronome. At each subsequent beat, again note and speak out the current and let a colleague record it. Repeat both sets of observations three of four times and find the mean value of current for each value of time.

Plot a graph between time t and current I, taking the latter along Y-axis, for both cases. In the first case (current rising), find from graph the time in which (I_0-I) reduces by a factor of 2.72. This is the time constant of the inductor. In the second case (Current falling), find from graph the time in which current I reduces by a factor of 2.72. Are the two time constants equal within experimental error?

Time constant from the graph of current rising =

Time constant from the graph of current decaying =

Note: 1 After passing the current I_0 when it decays to zero, the core of the inductor retains some of the magnetisation, that it acquires in the magnetic field of the current. Thus if initially the core had no magnetisation, then during rising current it has to be fed more energy to build up its magnetisation by induction, than it gives back during current decaying. Thus the time constant during current rising is more than that during decaying. However, after once passing the current, when you pass the current second time, the difference between the two time constants will be negligible.

2. Because magnetisation of iron core (measured by magnetic induction B) is not proportional to magnetic field produced by the current in the coil, inductance of the inductor varies significantly with current. Thus your time constant obtained from the graph may be slightly different for different current ranges, if your measurements are accurate enough (e.g. for decay of current from 4.08 mA to1.5 mA and from 2.04 mA to 0.75 mA, being less for the former range).

TOPIC VII BEHAVIOUR OF INDUCTOR AND CAPACITOR ON PASSING AN A.C. THROUGH THEM.

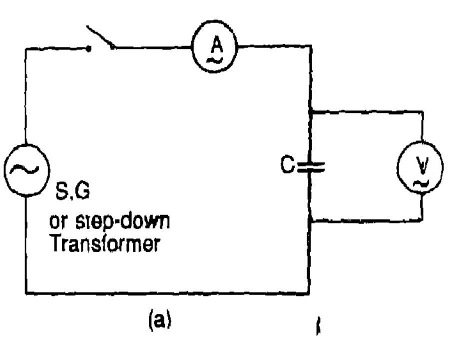
4.22 (Experiment): To study the characteristics of a capacitor when an alternating voltage is applied.

Apparatus: An audio-oscillator (also known as signal generator), an a.c. voltmeter, (0-25 V) an a.c ammeter (0-25 mA), several paper capacitors of different capacitances (0 10μF, 0.20μF, ... 1 00 μF).

Procedure . In this experiment you are to study how the r.m s. current passing through a capacitor depends on its capacitance and on r.m s voltage and frequency of applied alternating voltage[6] The experiment is done in three parts Firstly, for a given capacitor the frequency is kept constant and its voltage is varied Secondly, for a given capacitor, the voltage is kept constant and the frequency is varied Thirdly, the frequency and the voltage are kept constant and C is varied.

(a) Voltage-current Relationship for Capacitor at Constant f

Connect the capacitor, say 0.2 μ F, through the ammeter and a tapping key to the audio-signal generator, Fig. 4.26(a). Select the generator frequency to be 1000 Hz. Start with the lowest value of generator voltage. Record the current I in the ammeter A and voltage V across the capacitor in the voltmeter.



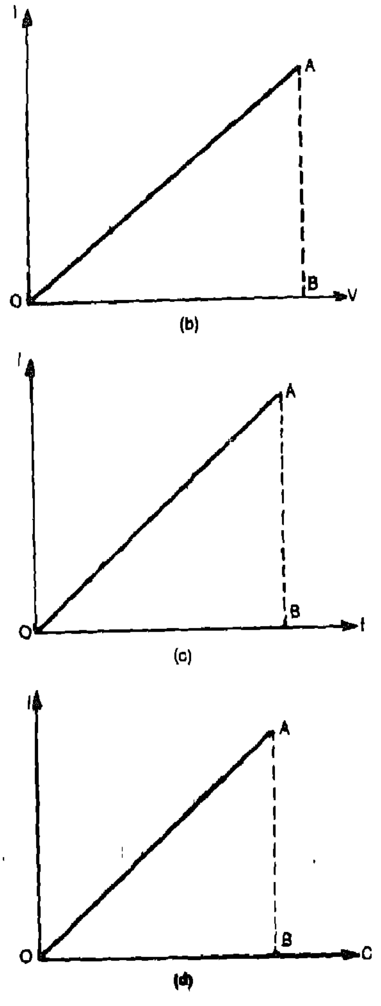


Fig. 4.26 *Study of the characteristics of a capacitor when a.c. passes through it.*

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[6]When an alternating current is passing in a circuit, "r.m.s. current" means the root mean square value of the current. Since the current in the circuit continuously changes, this is a kind of average value which is used to represent the magnitude of the current. All a.c. ammeter are so calibrated as to directly read the r m.s. value Similar considerations apply to the term "r.m.s voltage."

Repeat with successively higher voltage and record the current for each value of voltage. Plot a graph between V (as absicissae) and I (as ordinates), Fig. 4.26 (b).

If the graph is a straight line passing through the origin, it implies that the current in the circuit is directly proportional to the voltage across the capacitor, i.e. that ohm's law applies. Thus a given capacitor offers a constant opposition to passage of alternating current of a given frequency

Find the slope of the graph:

$$\text{Slope} = \frac{\text{Change in the current in the circuit}}{\text{Change in the voltage across the capacitor}}$$

$= AB/OB$

This slope gives the inverse of the *reactance*, X_c of the capacitor at 1000 Hz. It is a measure of the opposition offered by the capacitor to passage of a c. at 1000 Hz.

The reactance of a capacitor is $X_C = \dfrac{1}{2\Pi f_c}$ where C is the capacitance of the capacitor. Using the value of C mentioned on the capacitor, calculate X_c and compare your result.

Note : It is important that with no current passing in the circuit, the needles of ammeter and voltmeter are at their zero marks. Check that it is so. Tap the instruments lightly to reduce friction. If the needles are not at their zero marks, bring them on to the zero marks by the adjusting screw provided in each instrument.

(b) *Study of Current-frequency Relation for a Capacitor at Constant V*

Adjust the output voltage of the generator say 20 V and keep it constant. Select a low frequency, say 100 Hz and note I for the capacitor of say, 0.1μF. Increase the frequency, f in steps of 200 Hz upto 2 kHz. Note the corresponding values of I and record them in a table. Plote a graph between I (as ordinates) and corresponding values of f (as abscrissae), Fig. 4.26 (c). If the graph is a straight line passing through the origin, it means the greater the frequency the less is the opposition of passage of current, or the reactance, i.e. $X_c \alpha 1/f$.

It is possible that as frequency increases the output voltage of the generator may change. Hence check up the voltmeter reading at each

Observations:

Frequency of generator, f = 1000 Hz.

Current, I (ampere)	
Voltage, V (Volt)	

Slope of the graph $\dfrac{\Delta I}{\Delta V}$ = $\therefore X_c =$

Stated value of $C =$ $\therefore X_c = \dfrac{1}{2\pi FC} =$

observation. If need be, adjust output voltage knob to keep V constant.

(c) *Study of Current-capacitance Relation for Constant V & f:*

Now keep the generated voltage constant at 20V and frequency at 200 Hz throughout the experiment. For C=0.10 μF. Note the current I. Increase the value of C by inserting bigger capacitors in the circuit and note I for each C. Plot a graph between I (as ordinates) and C (as abscrissae) Fig. 4.26 (d). If this graph is a straight line passing through the origin, it means that greater the capacitance the less is the opposition to passage of current, or reactance, i e.

$$X_c \propto \frac{1}{C}$$

It is possible that as the capacitance and circuit current increases, the output voltage of the generator may decrease. Hence check up the voltmeter reading at each observation. If need be, adjust output voltage knob to keep V constant.

Note. Working without the signal generator. If you do not have the signal generator, you can still do parts (a) and (c) of this experiment using your a.c. mains. Use a step-down transformer which give various voltages in steps in the range 0-12V or 0-24 V at 50 Hz. At such low frequency, current in the capacitor is small and your a c. ammeter has to be of range 0-5 mA or 0-1 mA. Use a rheostat in series with ammeter for the part (c), in order to adjust the current, so that voltmeter reads constant voltage for all readings.

4.23 (Experiment): To study the characteristics of an R-L circuit driven by an a.c. source.

Apparatus: An audio-signal generator, an a c. voltmeter, an a.c. ammeter, several inductor coils of large L (say 0.1 H, 0.2 H, 0.3 H, 0.5 H, 0.7 H, 1.0 H). A variable inductor may be used in which the inductance can be changed at will, by adjusting the position of its iron core).

Procedure: This experiment is also done in three parts as in the previous experiment. First, for a given inductor, the frequency of the signal generator is kept constant and its voltage is varied and its effect on current is studied. Secondly, for a given inductor, the voltage is kept constant and the frequency is varied. Thirdly, the frequency and the voltage are kept constant and L is varied.

(a) *Current-voltage Relationship for an Inductor at Constant f*

Connect the inductor (whose resistance is R and L=0.2 H, say) through the ammeter and a tappig key to signal generator, (Fig. 4.27 a).

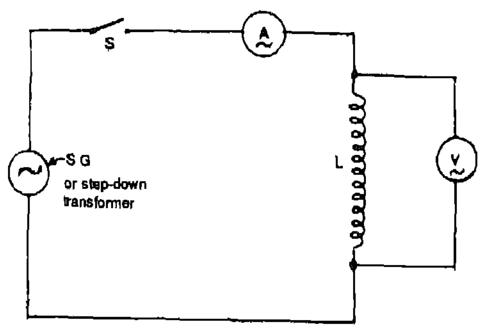


Fig. 4.27 (a) Study of the characteristics of an inductor when a.c. passes through it.

Select the generator frequency to be 1000Hz. Start with the lowest value of signal generator voltage, V. Record the current I passing in the circuit and voltage, V, across the inductor. With successively higher voltages applied on L, record the current passing in the circuit for each voltage. Plot a graph between I (as ordinates) and V (as abscissae), (Fig. 4.27b).

If the graph is a straight line passing through the origin, it implies that the current in the circuit is directly proportional to the voltage across the inductor, i.e. that the Ohm's law applies.

The slope of the graph·

$$\text{Slope } \frac{I}{V} = \frac{AB}{OB}$$

This slope gives the inverse of the reactance, X_L of the inductor at 1000 Hz, i.e. $X_L = \frac{OB}{AB}$

The reactance of the inductor is $X_L = 2\pi fL$, where L is the inductance of the inductor. Thus find the values of L using the relation.

$$L = \frac{X_L}{2\pi f}$$

Observations:

Frequency of generator, f = 1000 Hz

Current, I (ampere)	
Voltage across inductor, V (Volt)	

X_L = ______________ohm

L = ______________henry

Notes: The note about zero positions of needles of ammeter and voltmeter explained in previous experiment is important for this experiment too.

(b) *Current-frequency Relationship for an Inductor at Constant Voltage.*

Adjust the output voltage of the generator, say 20V and keep it constant. Start with a medium frequency, say 1000 Hz and note I. Increase the frequency in steps of 1000 Hz up to 10k Hz. Note corresponding values of I and record them in a table.

It is possible that as frequency increases the output voltage of the generator may change Hence check up the voltmeter reading at each observation. If need, be, adjust voltage knob to keep V constant

Plot a graph between I (as ordinates) and corresponding values of f (as abscissae), (Fig 4.27c). Plot another graph between I and $1/f$ (Fig. 4.27b). If I increases with $1/f$ and graph is straight line passing through origin, it means that reactance X_L is proportional to $(1/f)^{-1}$ i.e.f

(c) *Current-inductance Relationship for Constant V and f_L.*

Now keep the voltage of signal provided by the generator constant at 15V (say) and frequency 1000 Hz throughout the experiment. Start with the lowest value of L (i.e 0.1 H.) Note the value of I for each inductor coil connected in turn in the circuit (i.e for each L) Record the values of I against corresponding values of L in a table.

Plot a graph between I (as ordinates) and L (as abscissae), (Fig 4.27e) Plot another graph between I and $1/L$ (Fig.4 27f). If the graph between I and 1/L is a straight line passing through the origin, it means that reactance X_L is proportional to $(1/L)^{1}$ i.e L

Note: 1. Working without the signal generator. If a signal generator is not available, you can still do parts (a) and (c) of the experiment, using your a.c. mains Use a step-down transformer which gives various voltages in steps in the range 0-12 V or 0-24 V at 50 Hz. At much low frequency, current in the inductor is much larger and you must choose an a.c. ammeter of appropriate range.

2. In part (c) your voltmeter must read constant voltage for all readings.In case of signal generator, this can be done by adjusting its output voltage knob. In case of step-down transformer, use a shoestat in series with ammeter.

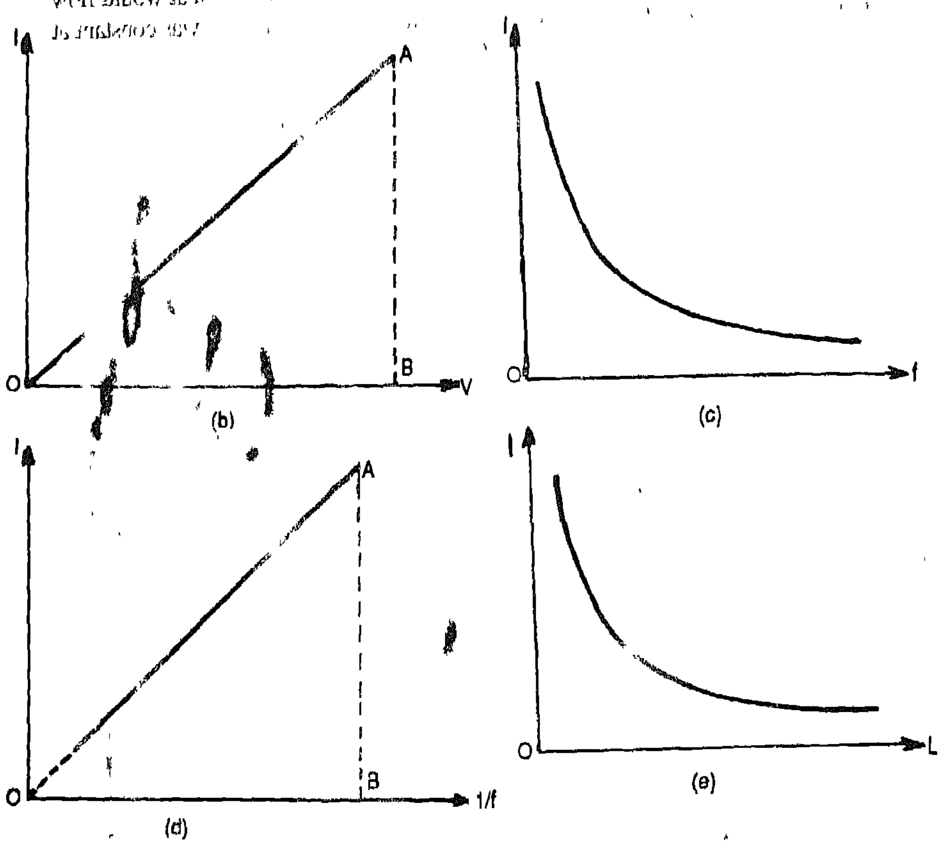


Fig. 4.27 (, b, c, d, e)

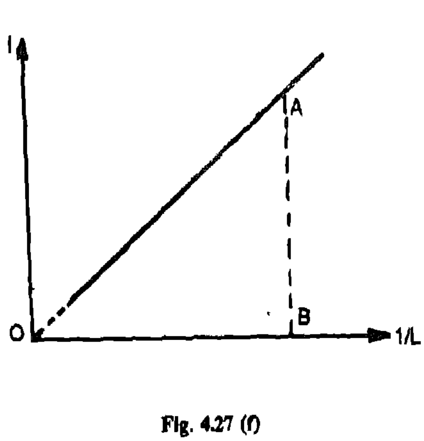


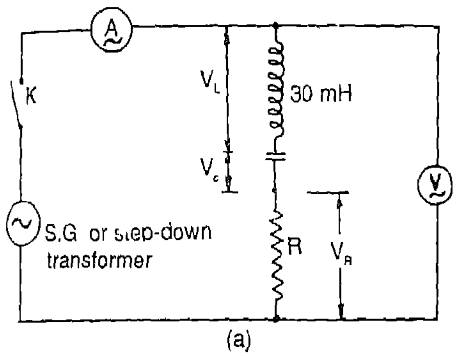
Fig. 4.27 (f)

3. Note that every coil has some resistance of its windings. This resistance has not been shown in the circuit. In fact for frequencies above 1000 Hz, resistance is small compared to reactance and therefore has not been shown in the circuit.

4.24 (Experiment): To study the characteristics of a series resonance circuit

Apparatus: Signal generator with frequency scale, high resistance a.c. multi-voltmeter (0 to 30/75/150V, 10000 ohm/V), a.c. ammeter (0-100mA), a 1-μF capacitor, an inductor of about 30 mH.

Method. Connect the circuit as shown in Fig. 4.28-a A single multimeter is used to measure



(a)

Fig. 4.28 *Study of the characteristics of a series resonance circuit.*

voltages, which may vary over a wide range during the experiment The resistor R is the series resistor connected in the circuit.

Ammeter measures the current, I, passing through the resistor, inductor and capacitor in series, as the current through voltmeter never exceeds 0.1 mA and is negligible.

Set the signal generator output to a low value, say 2 V, when the switch K is open and then do not alter this setting throughout the experiment, so that its output voltage V_c (under no load condition) is same at whatever frequency observations are taken.

Start with a low frequency, f, (say 100 Hz), and record values of I, and V. Keep the value of external resistor R connected in series with L and C at zero ohm. Increase the frequency in steps through a suitable frequency range, say 50 to 5000 Hz and note each frequency by the scale provided on the signal generator. At a certain frequency, f_r the current becomes maximum. This is called *resonant frequency*. Record the readings around this frequency, by taking smaller steps for increasing the frequency. For each frequency, calculate the reactance of the LC combination, $X = V/I$. Also calculate for each frequency the current I' that would flow in the circuit, if the value of V was constant at V_o:

$$I' = I\frac{V_o}{V}$$

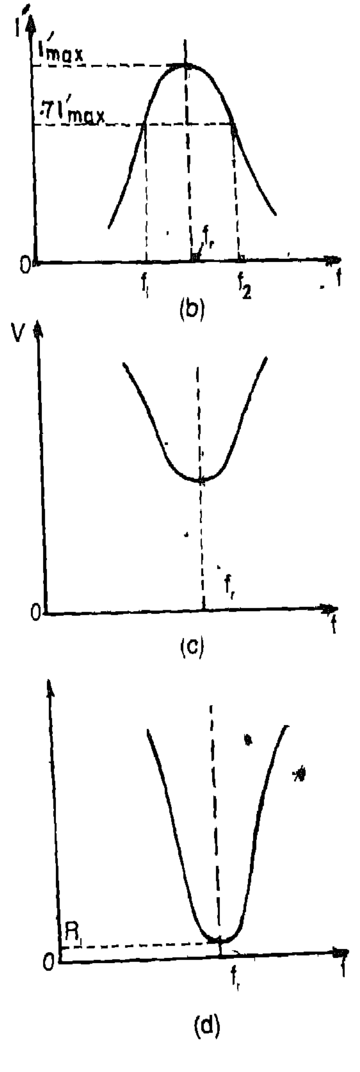


Fig. 4.28 (b, c, d)

To study as to what happens at resonance, plot graphs for I', V and X against frequency, (Fig. 4.28, b & d).

Observations : Output voltage of generator, V_0 $L=$ ___ $C=$___ $f_r=1/(2\pi\sqrt{LC})=$___Hz

S.No.	f. (Hz)	I (A)	V (V)	$I'=\frac{IV_o}{V}$ (A)	$X=\frac{V}{I}$ (ohm)

Resonant frequency from I' vs f graph (Fig. 4.28 b) = _________ Hz

Resonant frequency from V vs f graph (Fig. 4.28 c) = _________ Hz

Resonant frequency from X vs f graph (Fig. 4.28 d) = _________ Hz

R_i the internal resistance of L & C (Minimum value of X) = _______ ohm

Quality factor $Q_o = 2\pi f_2 L/R_i$ = _________

Half point f_1 = _________ Hz, f_2 = _________ Hz, $f_2 - f_1$ = _________ Hz

Notes : Output impedence of generator. It is notworthy that as current approaches its maximum value, the voltage V measured across and approaches a minimum. This situation is similar to what happens with any cell which gives a lower potential difference when a large current is drawn from it. It is due to an *output impedence* of the signal generator which has similar role as the internal resistance of the cell. You can calculate the output impedance using the relation :

$$\text{Output impedance} = \frac{V_o - V_{min}}{I_{max}}$$

2. *Phase relation between X_L & X_C . At frequencies substantially away from resonant frequency, individual voltages* V_L and V_C may be larger than the output voltage of the oscillator and V is quite closely equal to their difference. At one or two frequencies you may like to check up this fact by actually measuring V_L and V_C. Thus it should be clear that a.c. voltages across inductor and capacitor are in phase opposition, and consequently inductive and capacitative reactances X_L and X_C are opposite in character. The a.c. current in circuit lags behind V_L by 90° and V_C lags behind the a.c. current by further 90°. Hence, V_L and V_C differ by 180° in phase.

3. *Why to experiment with low voltage* : As we approach resonance frequency f_r, both V_L and V_C increase enormously and may cause damage to insulation. For this reason it is advised to set the signal generator at a rather low voltage. Also the capacitor and inductor should be rated at 300 V, atleast

4. *Why not keep V constant* If you adopt a procedure in which at each frequency when you measure I, you adjust the output knob of signal generator so as to keep V constant, the experiment will be simpler to understand. However, you may not be able to adopt this procedure, if your inductor and capacitor are good. To keep V constant you may need such a large current at resonance which your signal generator may not be able to give Also, V_L and V_C may reach such a high value at resonance, which may damage the inductor or the capacitor.

5. *Internal resistance of resonance circuit* : Resonance occurs when opposite reactances X_L and X_C are equal. If the capacitor and inductor are ideal and have no internal resistance, their combined reactance would be zero at resonance. Thus current at resonance would be infinite, except that it is limited by the output impedance of the signal generator. In the

inductive coil, the internal resistance is due to finite resistance of its winding and hystersis losses in its iron core. In the dielectric of the capacitor too, there are energy losses. The minimum value of X at resonance (when R is zero) represents this internal resistance:

$$R_i = \frac{V_{min}}{I_{max}}$$

6. *Resonant frequency* : At resonance, $X_L = X_C$ i.e., $2\pi f_r L = \frac{1}{2\pi f_r C}$ $\therefore 4\pi^2 f_r^2 = \frac{1}{LC}$

or, $f_r = \frac{1}{2\pi\sqrt{LC}}$

Calculate f_r using this equation, if values L and C are known, and compare with your experimental result.

7. *Quality factor* : The magnitude of voltage drop across L at resonance is $V_L = X_L I_{max} = 2\pi f_r L\, V_{min}/R_i = Q_O V_{min}$. Here $Q_O = 2\pi f_r L/R_i = \frac{1}{2\pi f_r C R_i}$ is the quality factor at resonance. It is the ratio of reactance of L (or of C) to the value of X, both taken at resonant frequency f_r. Since Q_o is a number greater than 1, the voltage drop across C or L would the be greater than V_{min}, the voltage drop across the voltage drop across L and C combine. Calculate the value of Q_o, knowing the values of F_r, R_i, L and C.

By adding a resistance R in series with the resonance circuit, you can effectively increase its internal resistance to $R + R_i$. Then quality factor would be

$$Q = \frac{2\pi f_r L}{R + Ri} = \frac{1}{2\pi f_r C\,(R+R_i)}$$

8. *Half points* : On the I' vs f graph, find two frequencies f_1 and f_2 where the current has its value equal to 70% of the current at resonance. These frequencies are known as *half points*, because the power consumed in the circuit at these frequencies is half the power consumed at resonance, subject to condition that constant a.c. potential difference is applied to the resonance circuit. Find the difference $f_2 - f_1$.

9. *Working without the signal generator* : If a signal generator is not available, the series resonance can still be studied by using your a.c mains and a step-down transformer. Use the variable inductor of experiment 4 23 in series with a capacitor of appropriate value, so that resonance at 50 Hz may take place with roughly middle value of the variable inductor. As the frequency is constant, method of the experiment as described above, will also have to be altered a little.

Exercise : 1. Increase the resistance of resonance circuit by adding an external resistance R and take observations for I as function of frequency. Repeat the measurements once again with a still larger value of R. In each of the three sets of observations for I as a function of f (including the one with $R = 0$), convert the values of I to I', the current that would pass keeping $V = V_o$. Then convert values of I' as percentages of its value at resonance in that set.

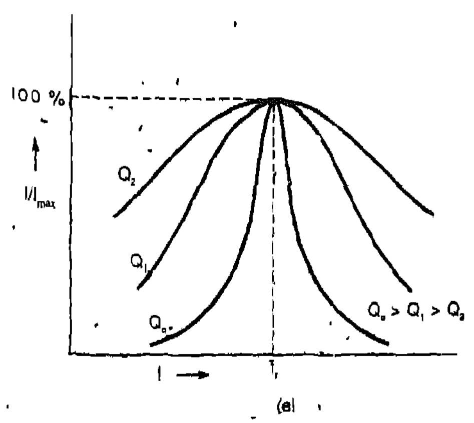


Fig. 4.28 (e)

Then plot these percentage values of I' against f on the same graph. So you get curves for three values the quality factor, Q_0, Q_1 and of Q_2, as shown in Fig. 4.28(e). Do you find that with smaller values of R (i.e. larger value of quality factor, Q) the resonance is sharper ? Hence, Q is also called *sharpness of resonance.*

2. Take another capacitor whose capacitance C is *not* known. Connect it in series with an inductor of known L and measure their f_r by series resonance circuit. Then using the equation $f_r = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$ find the value of unknown capacitance. In like manner, take another inductor whose L is *not* known. Combine it with a known capacitor in series and find its inductance.

4.25 (Experiment) : To study the characteristics of a parallel resonance circuit.

Procedure : Connect the inductor and capacitor in parallel as shown in figure 4.29. The

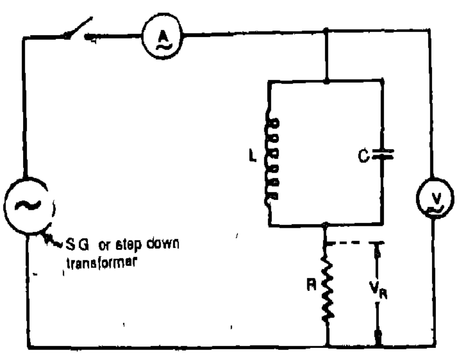


Fig. 4.29 *Study of the characteristics of a parallel resonance circuit.*

ammeter measures the combined current of L and C. Set the signal generator at its highest output voltage and measure its value, V_0 (under no load condition) and do not alter the [illegible] the experiment [illegible] frequency, say 100 Hz, and [illegible] current, I, and voltage V, keeping resistance R equal to zero Increase the frequency in steps through a suitable frequency range, say 50Hz to 5000 Hz and measure I and V at each frequency. For each frequency, calculate the current I' that would flow if V was kept constant at a value V_0. Plot a graph taking values of I' along Y-axis and corresponding values of f along X-axis. Find the reactance of the circuit, X (= V/I) for each frequency and plot it as a function of frequency

Then I' versus f graph is found to be the exact opposite of what is obtained for the series resonance circuit Whereas the current in the series circuit exhibited a maximum at the resonance frequency, the current in the parallel circuit passes though a minimum value at the resonance frequency f_r. Find this frequency from the I' vs f graph. For greater precision in finding f_r, crowd the readings around this frequency by taking smaller steps of increasing the fequency for various observations.

Observations : Output voltage of signal generator, V_0. = ____________ V

S.No	f(Hz)	I(A)	V(volt)	I'(A)	X (Ω)

Resonance frequency by I' versus f graph

= ____________ Hz

L = ________ H, C = ________ F,

$f_r = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$ = ____________ Hz

Max. Value of X = ____________ ohm

Quality factor Q_0 = $\frac{\text{Max value of X}}{2\pi f_r L}$

Half point f_1 = ____________ Hz, f_2 = ____________ Hz, f_2-f_1 = ____________ Hz

Notes : 1. ***Resonant frequency:*** To a close approximation, the resonance frequency, f_r in parallel resonance circuit is given by the same equation as that for a series resonance circuit, namely

$$f_r = \frac{1}{2\pi}\frac{1}{LC}$$

Use the same inductor and capacitor in this experiment as were used in the series resonance experiment. Thus check up if you get same resonance frequency in both experiments. Also test the above relationship by inserting the values for L and C quoted by manufacturer in the above equation and comparing the calculated value for f_r with the value obtained from the graph.

2. *Quality factor/sharpness of resonance:* In the series resonant circuit, quality factor was the ratio of reactance of L to the value of X, both at resonant frequency. In parallal resonant circuit, because X is maximum at resonance, the quality factor is

$$Q_o = \frac{\text{Max. Value of } X}{\text{Reactance of inductor at resonance}} = \frac{\text{Max. value of } X}{2\pi f_r L}$$

Thus calculate the value of Q.

3. *Half points:* Find the half points i.e. the frequencies f_1 and f_2, where I' is 2 I' min, with the help of I' vs f graph. Then find the difference f_2-f_1;

4. *Working without the signal generator:* If a signal generator is not available, the parallel resonance can still be studie by using your a.c. mains and a step-down transformer. Use the variable inductor of experiment 4.23 alongwith a capacitor of appropriate value, so that resonance at 50Hz may take place with roughly middle value of the variable inductor. As the frequency is constant, the method of doing this experiment as described above, will also have to be altered a little.

Exercise : Take an[illegible] whose capacitance [illegible] it in parallel with an [illegible] measure their resonance frequency, f_r by the parallel resonance circuit. Then using the relation:

$$f_r = \frac{1}{2\pi\sqrt{LC}}, \text{ i.e } C = \frac{1}{4\pi f^2 L},$$

find the value of the unknown capacitance. In like manner take another inductor whose L is *not* known. Combine it with a known capacitor in parallel and find its inductance.

TOPIC VIII L-C OSCILLATIONS

4.26. (Demonstration): To demonstrate the oscillations in a series *L-C* circuit.

Connect an inductor of about 2500 H (see appendix 11) and a paper capacitor of 2μF (750 volt rating) in series and then to a DC power supply of 300 V through a two-way key, K (Fig.4.30). When the lever of K_1 is moved to

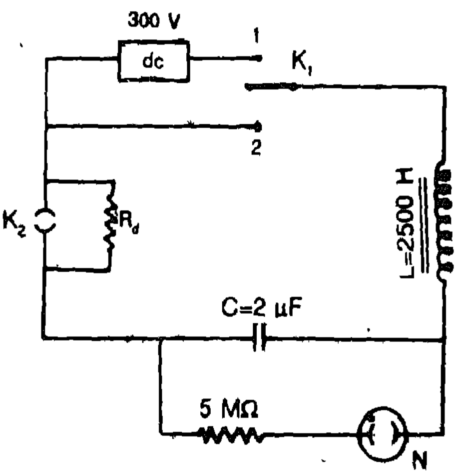


Fig. 4.30 *Electrical circuit for demonstrating series LC oscillations.*

position 1, power supply is connected in the circuit and the capacitor is charged. When the lever is moved to position 2, power supply is not in the circuit and the capacitor is discharged. A resistance R_d of 50 kΩ shunted by plug key K_2 can be brought in the circuit whenever desired, by openings the key K_2

Terminals of the capacitor are connected to a neon indicator lamp, N through a 5 MΩ resistor. Whenever the capacitor is charged to a voltage above about 150 volt, the lamp indicates it by a glow, because a current passes through it. The resistance of 5 Mπ in series with it ensure that only a weak current passes in the lamp, with does not cause significant damping of free electrical oscillations in the inductor and capacitor in series.

Let the key K_2 be closed initially so that R_d is zero. When you move the key K_1, an oscillating potential difference develops across the capacitor, its frequency, f_r is:

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2x3.14\ 2500x2x10^{-6}} = 2.25 \text{ Hz}$$

The graph in figure 4.31 (a) shows how the

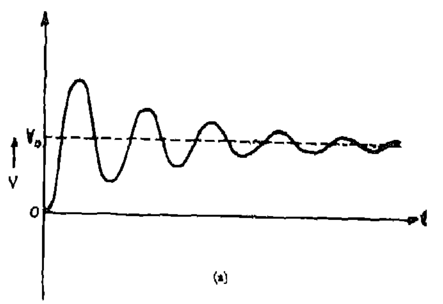


Fig. 4.31 a

potential differences across the capacitor changes. It does not simply rise to value Vo, the voltage of the power supply. It reaches up to about 2 V_o initially and oscillates up and down. Ultimately the oscillations die out and it becomes equal to V_o. The oscillations are indicated by the flicker of neon lamp in the beginning As the oscillations die out, the flicker of the neon lamp also dies out and it glows with a constant brightness

When you move the key K_1 to position 2, the potential difference across the capacitor does not simply come down to zero values It reaches ($-V_o$) initially and oscillates up and down for some time, as shown in the graph in Fig.4.31b. The oscillations are again, indicated

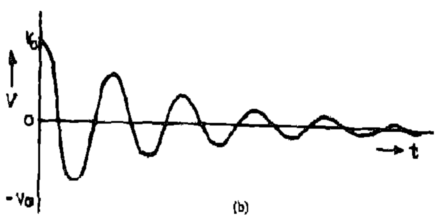


Fig. 4.31 b

by the flicker of the neon lamp Gradually the oscillations die out and the neon lamp also goes dark.

Next, let the key K_2 be open so that the resistance R_d of about 50 kΩ is in the circuit. Repeat the above procedure. This time you find that when K_1 is brought to position 1, neon lamp starts glowing without flicker, as the p.d. across the capacitor quickly rises to V_O without oscillations, as shown in Fig. 4.32 (a). When key K_1 is brought to position 2, neon lamp goes dark without flicker, as the p.d. across the condensor quickly comes down to zero without oscillations, as shown in Fig.4.32 (b).

Why oscillations occur, is easier to explain in the case when capacitor is discharged. As the capacitor discharges, current flowing through L develops energy of magnetic field in it. Thus the energy of capacitor is transfered to the

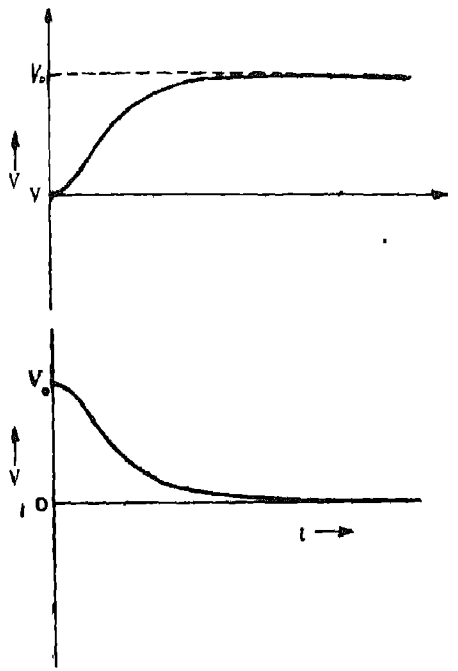


Fig. 4.32 (a, b)

inductor. After the p.d. across capacitor becomes zero, the inductor continues the flow of current by induced e.m.f., till the capacitor is charged to approximately same p.d. in opposite direction. Thus energy of magnetic field is transfered to capacitor, except for a small part of it converting into heat (the circuit has some resistance, though small). Thus mutual energy transfer continues until entire energy initially stored in the cpacitor is converted into heat, due to finite resistance of the circuit. The greater the circuit resistance, the more quickly oscillations die out. When the circuit resistance is more than a certain value, called *critical damping resistance*, no oscillations take place in the circuit.

4.27 (Demonstration): To demonstrate the oscillations in a parallel L-C circuit.

Connect a capacitor, C of about 2 μF (750 volt rating) with an inductor L of about 2500 H (see appendix 11) in parallel (Fig. 4 33). Connect

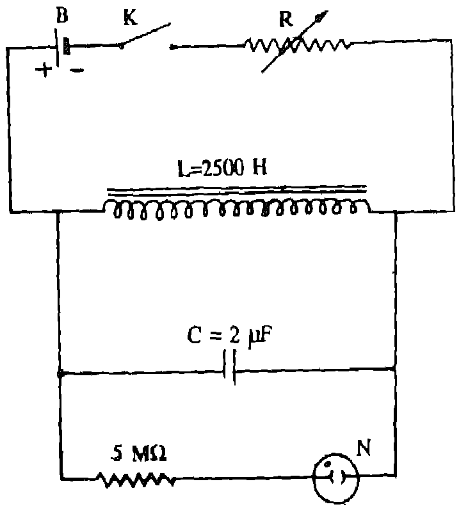


Fig. 4.33 *Electrical circuit for demonstrating parallel L C oscillations*

it to battery B through a tapping key k, and a resistance box R Connect the two terminals of the capacitor to a neon indicator lamp, N, through a 5 MΩ resistor.

With the key K closed, let a steady current of roughly 6 mA pass in the inductor. Thus if e.m.f. of the battery is 6V, you keep R = 750 ohm and resistance of the copper windings of the inductor is 250 ohm. There is a small potential difference V_0 across the plates of the capacitor too, which is equal to resistive potential drop across the coil of the inductor.

Now, when you open the key K, the neon lamp flickers for some time and then goes dark.

It shows that oscillating voltage had developed across the capacitor. These electrical oscillations are set up by the energy stored in the magnetic field of the inductor Graph shown in figure 4.34

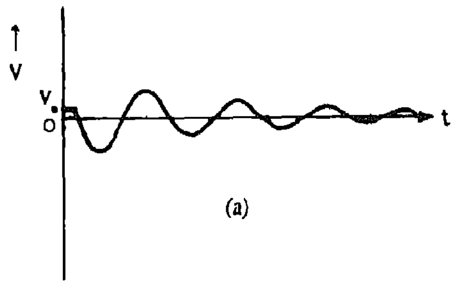


Fig 4.34 a

(a) shows how the p d across the capacitor varies with time

Energy stored in the inductor initially, can be increased by increasing the initial current in it For example, keep $R = 350$ ohm, so that the circuit resistance is 600 ohm and current is 10 mA This time, as you open the key K, the neon lamp flickers with much brighter glow. Due to greater energy stored in the inductor, the first peak voltage of the capacitor in this case is larger than that in the former case, as shown in the graph in Fig.4.34(b). This time too, as

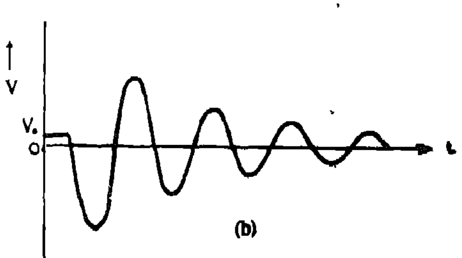


Fig. 4.34 b

the oscillations die out, the neon lamp goes dark, because the final p.d. across the capacitor is zero

With the values of circuit components equal to those given in figure 4 33, do not try to demonstrate this experiment with initial current in the inductor more than 20 mA. With larger initial current, the first peak of voltage developed across the capacitor may be so large that it may damage the insulation in the capacitor or the inductor.

4.28 (Demonstration) : To demonstrate that a large e.m.f. is induced when direct current is switched off in an inductive circuit.

The back e.m f in an inductive coil cannot exceed the e m.f of the battery when the current is switched on, because the resultant of the two must pass (conventional) current from positive terminal. However, when d c. is switched off, the situation is different.

Make circuit as shown in figure 4.35. N is

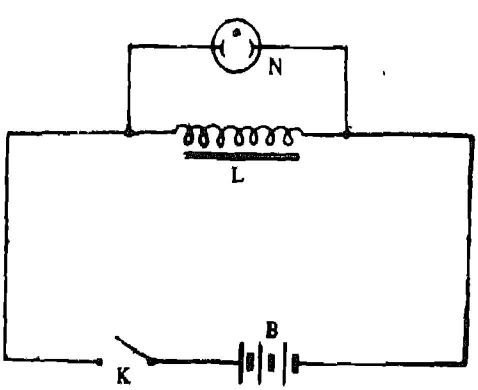


Fig. 4.35 *When current in the circuit is stopped then only the neon bulb N flashes.*

a neon lamp fitted into holder with terminals. B is a dry cell battery of 3 V or a lead accumulator of 2 V. The coil L has a lage number of turns. Close the key K and observe that the

neon lamp does not light up. It so happens because the striking voltage for neon lamp (about 150 V) is considerably larger than the modest 2 to 3 volt which battery B is capable of supplying.

Now open the key K The lamp is seen to flash, indicating that in the inductance L a large induced e.m.f. has been generated tending to maintain the flow of curent through the coil after the source of e m.f. has been switched off.

According to Faraday's law, this large induced e.m.f. is generated due to the fact that when key is opened, current through B instantly stops. Thus rate of decrease of magnetic flux in the coil is very large and a large e m.f is induced, which passes a pulse of electric current in the lamp.

Note 1. *Energy in a magnetic field.* A question may be asked here that when the source of e.m.f. (i.e. the battery B) has been cut off, where does the energy which flashes the neon bulb come from. It comes from the magnetic field associated with the coil L with current passing through it. Thus this experiment also vividly demonstates that a magnetic field contains energy.

2. *Definition of self-inductance* · The phemenon of induced e.m.f. existing in the same coil in which the changing current passes is called *self-inductance* Mathematically the self-inductance (L) of a coil is defined by the equation

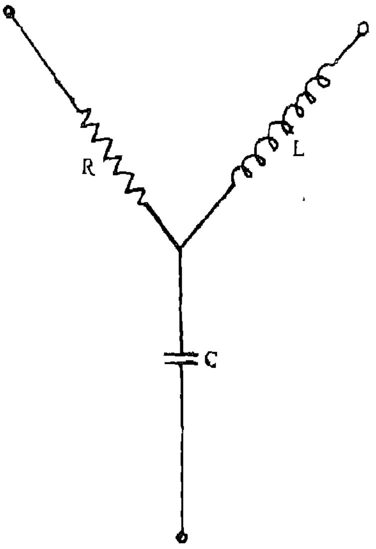
$$E = -L \frac{di}{dt}$$

Where E is the induced e.m f., and $\frac{di}{dt}$ is the is the rate of change of current passing $\overline{dt}$ through the coil. Negative sign in the above equation only indicates that the direction of induced e.m.f. is opposite to the change in current and tends to maintain the current constant.

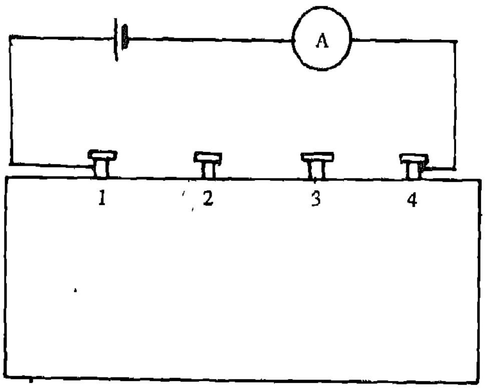
3. *Mechanical analogy for self-inductance.* The above equation is quite similar to the following equation in mechanics. Force exerted by a moving object on an external agency due to its inertia = $-m\frac{dv}{dt}$, where m is mass and $\frac{dv}{dt}$ is rate of change of velocity i e. acceleration of the body Here too the negative sign only indicates that the direction of force is opposite to the change in velocity and tries to maintain the velocity constant Thus the role of *L* is an electrical system is similar to that of mass in a mechanical system For example, switching on a d.c. current in the coil is analogous to accelerating a hammer. Therefore, switching off this d c current is analogous to the hammer striking a nail when its motion is instantly stopped and it applies a large force on the nail

4.29 (Activity): Identification of the circuit elements (*L, C* and *R* concealed in a box (star-connections).

L C and *R* are connected as shown in Fig 4 36a



(a)
Fig. 4.36 (a)



(b)
Fig. 4.36(b)

with one terminal common. These elements so connected are placed in a box to which four terminals are provided (Fig 4 36b). Each terminal is connected to one end of an element with one of them common to all. Without opening the box the elements have to be identified. Take a battery and an ammeter and join them in series so that the two ends of series combination can be used as probes.

Hint· (a) When the circuit is completed through R only, the deflection in the millimeter is minimum.

(b) When the circuit is completed through L only, the deflection is maximum.

(c) Whenever C is in the circuit, no deflection is obtained.

Now note the deflection as described in the following table.

Conclusion:

1. Whenever 4 is connected, there is no deflection. Hence terminal 4 is one end of C.

2. 1-3 gives minimum deflection, 2-3 gives maximum deflection and 4-3 gives no deflection Therefore, terminal 3 is a common terminal

3. C is between 3 and 4, R is between 1 and 3 and L is between 3 and 2

4.30 (Activity): Make your own a.c. generator.

There are many designs of a.c. generator that you can make. Look up books on electricity projects or scientific hobbies in your school library and you will be able to locate a few designs Select the one you feel more interested in and make it. One design of such a generator has already been elaborated in Fig 4.19 and 4.20.

The key to generating a good strong current is (i) strong magnets, (ii) large number of turns of the coil in which induced e.m.f. is produced and (iii) higher speed of rotation.

Terminals Connected	*Current response*	*Inference*
1-2	minimum deflection	R may be there
1-3	small deflection	R may be there
1-4	No deflection	C is there
2-3	Maximum deflection	L is there
2-4	No deflection	C is there
3-4	No deflection .	C is there

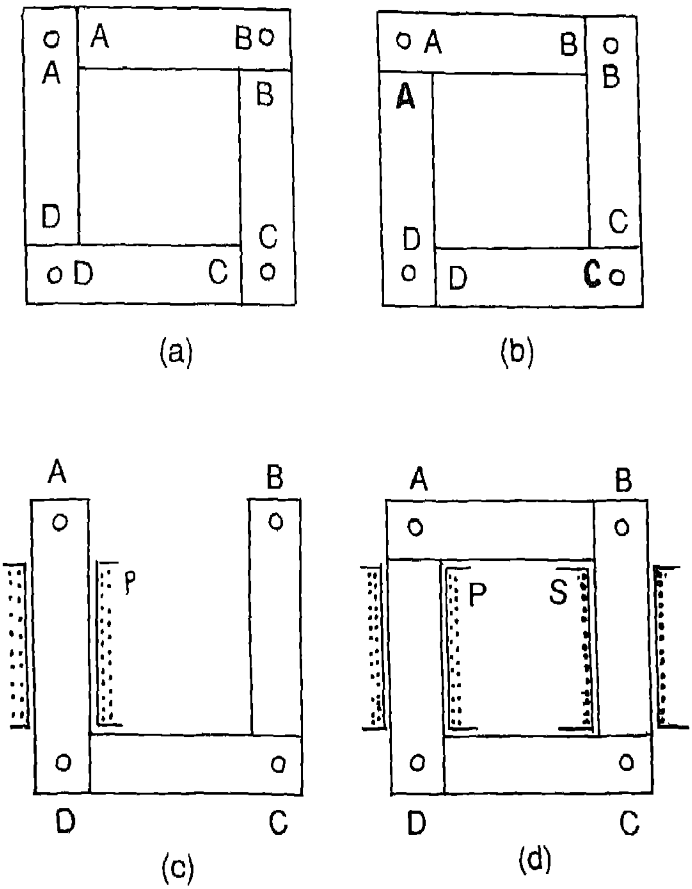


Fig. 4.37

4.31 (Activity) Make your own transformer. Purchase enamelled "transformer strips" of identical size made of soft iron available in an electrical market. Each strip shall have a hole at least at one end. Arrange four strips to make a square as shown in figure 4.37a. Over it lay another square of four strips as shown in fig.4.37b. The holes in the lower square coincide with those in the upper square. In the centre of each strip of lower square put a small drop of an adhesive (like araldite), which does not harden too quickly, so that strips on same side of the two squares later on stick to each other.

Over the second square lay a third one similar to Fig. 4.37a and then a 4th one similar to Fig. 4.37b. Continue the process till the pile is as thick as the breadth of the strips. Insert a nut and bolt in the hole at each corner of the pile and thus tie all the strips together tightly. See that outer and inner edges of the strips coincide, before tightening the nuts of the screws. Let this assembly of strips harden of 24 hours.

Now, remove nut-bolts from two holes at the ends of any one side (say AB) and pull it out with all strips of that side stick together. Make a card-board spindle of length slightly less than

the internal dimension of the square of strips. Core of the spindle is of square crossection and should slide easily over the side AD of the square. Wind in this spindle a coil of enamelled copper wire (at least about 1000 turns). Let us call it coil P (Fig. 4.37c). Make another identical spindle and wind another coil S, of between 50 to 100 turns on it by a thicker enamelled copper wire, say 18 SWG, and reassemble it as shown in Fig. 4.37d. In this assembly the magnetic flux created by any current in coil P is concentrated in the square shaped iron core. Thus any change in current in P induces an e.m.f. in coil S, which is proportional to number of turns in the coil S Connect the two leads of coil P, through a switch to 220 V a.c. mains. Measure the voltage th develops across the lead of coil S by an a.c voltmeter. If n_p is the number of turns in the primary coil, n_s the number of turns in secondary coil and E_p is the mains voltage applied on the primary coil, then you may expect a voltage E_s in the secondary to develop, given by the formula:

$$\frac{n_s}{n_p} = \frac{E_s}{E_p} \text{ i.e., } E_s = E_p \frac{n_s}{n_p}$$

In your improvised transformer measured value of E_S may be some what lower than that given by the above formula. It is due to the reason that entire flux created by coil P does not pass through coil S. If actual voltage in your secondary is 90% of that given by above formula, it implies that there is 10% flux leakage.

In a good commercially available transformer, flux leakage may be as small as 1% or even less. Hence the above relationship between E_p and E_s, may be taken as true for all practical purposes.

Note: Connect your improvised transformer to a.c. mains for short intervals only, lest it over heats, because it may have energy losses in it, i.e. its efficiency may be low.

Alternate Method: A transformer with a few secondary tappings can be made using the coil made for the demonstration experiment 4.15 (D) out of a condemned fluorescent tube choke. Refering to appendix 10, after you have identified the burnt coil of the choke, keep the good one on it. Replace the burned coil by a new one wound by a thick enamelled copper wire, making about 300 turns around a cardboard spindle, which can slip on to the core. Keep provision for three tapings, each of 100 turns, as shown in Fig. 4.38. There is no need to reas-

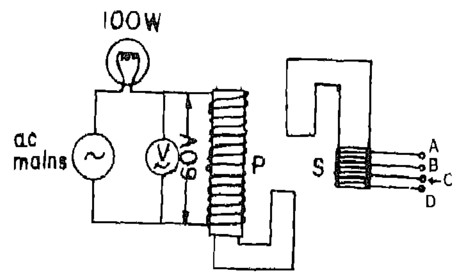


Fig. 4.38

semble the two J-shaped portions of the core in C-shape; keep them as they were originally fitted. The voltage is tapped from a.c. mains and applied across the primary through a 100 W incandescent lamp in series so as to drop the voltage from 220 V to about 60 V. Open circuit voltage V_B, V_C and V_D are measured across AB, AC. & AD respectively by using an a.c. voltmeter. It will be found that $V_D = 3V_B$, $V_C = 2V_B$.

The secondary coil S is removed along with half (J-shaped) core. The terminals A and D are

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Reference · Somnath Dutt, a *Low Cost Electromagnetic induction Kits out of condemned chokes of a fluorescent Tube*, Regional college of Education, Mysore - 570006 (1986)

connected to a few light emitting diodes (LED) in series. The LEDs will be found to glow even when the secondary is some distance away from the primary.

Connect a torch bulb across AD. As the core alongwith coil is gradually brought near the primary, the bulb starts glowing and will be gradually brighter This is so because as the secondary is gradually brought closer to the primary, more and more flux passes through it

Connect an 8 ohm 10 cm diameter speaker to AD As the secondary is brought near the primary a 50 cycle hum will be heard from the speaker, which gradually becomes louder.

THEME V

OPTICS AND MODERN PHYSICS

TOPIC 1 · RECTILINEAR PROPAGATION OF LIGHT

5.1 (Activity): Shadow formation

Make shadow of an object on a screen. Use an automobile lamp with a short filament (6V, 24W) as source of light, you can consider it like a point source of light. Observe that the shadow is of same shape as the object Measure I, the height of shadow, O, the height of object, u, the distance of object from light source, and v, the distance of shadow from light source and check up that $\frac{I}{O} = \frac{v}{u}$. This result proves that light travels in straight lines.

5.2 (Experiment): To study limitations to rectilinear propogation of light on passing through a narrow gap.

Apparatus: A fine slit of uniform width equal to thickness of a blade (appendix 12), laser or line source of llight (6V, 24W automobile lamp), white 30 cm scale, screw gauge/travelling microscope.

Procedure If a laser, L is available let its beam of light pass through slit S (Fig.5.1). Because laser beam is a parallel beam of light you expect illumination along a line on the screen whose width PQ may be equal to width of the slit. In fact you observe a much wider line. Measure its width, x by the scale keeping the screen at a distance d (about 3 m) from the slit and measure it too. There are also fainter coloured fringes parallel to this line of light but leave them. This light is a wave motion of wave length λ, which is given. Measure width of slit a, either by travelling microscope or by measuring thickness of that blade (by screw gauge) by which you made the width of the slit. Thus compute 'spread' of the beam equal to $\frac{x}{d}$ radian and check up whether it is also equal to $\frac{2\lambda}{a}$.

Using the automobile lamp L, which is a short line source of light, you can do this experiment in a semi-dark room at least 9 m long, as most Physics laboratories are. Place the line source of light vertically near one wall A of the laboratory (Fig 5.2a). Hold a good spectable lens C, of diameter 50 mm and power +0.5 D (i.e. convex lens of focal length 2 m) in a stand

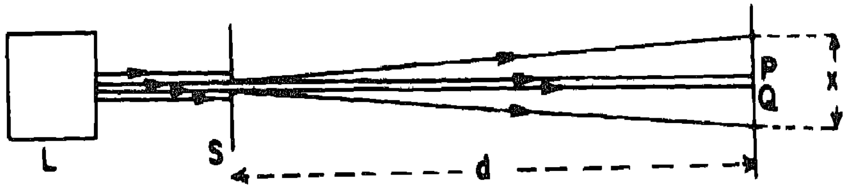

Fig. 5.1

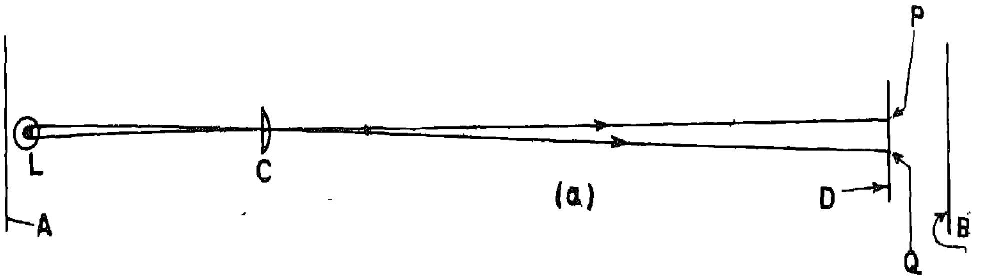

Fig. 5.2a

with concave side towards the lamp. Adjust its position so as to project an enlarged image of filament on a white scale, D fixed horizontally in a clamp stand near the opposite wall B Measure the width PQ of the image of the filament.

Now cover with paper a part of the lens on the side of the screen and observe that it only decreases the brightness of the image Reason is that as the exposed area of lens decreases, less of light energy reaches the image. It does not affect length and breadth of the projected image. Next, insert the slit, S, close to the convex lens C, on the image side of the lens and parallel to the vertical image (Fig.5.2b). Observe that not only the image becomes fainter, but also it becomes wider. It has highly blurred vertical boundaries. It is clear from this experiment that when light passes through the narrow slit, principle of rectilinear propagation of light breaks down and it is spread horizontally by the vertical slit.

This image may be too faint to be seen on the white scale due to some general illumination in the room. Cover the automobile lamp with a black cover to minimise the general illumination. Light of the lamp should reach the lens through a hole in the cover Now, position yourself between the scale and wall B. Keep the scale markings towards yourself. Look at the slit over the edge of the scale. Thus locate on the scale, the region in which you can see yellowish light of the bulb coming through the slit. At boundaries of this region you may find red light coming from the slit, as the red component of light spreads more than other colours Thus estimate the width, x of the region in which red light spreads by the slit. Also measure the distance d between scale and the slit. Then calculate the 'angular spread' θ of the red light due to the slit:

$$\theta = \frac{x - PQ}{d}$$

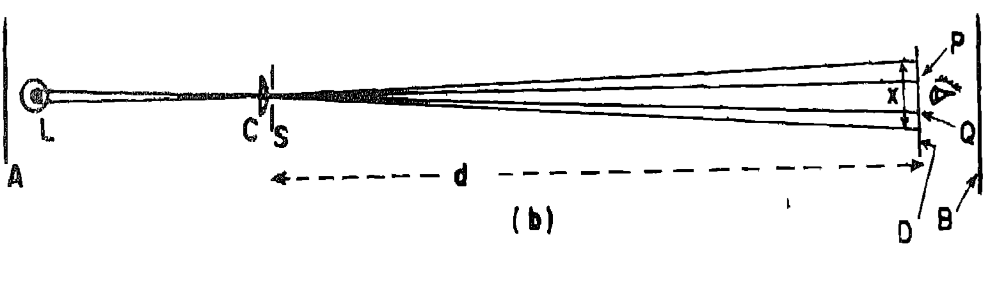

Fig. 5.2b

According to wave theory of light, if a is the slit width (which is known) then angular spread of light due to slit is $\theta = \frac{2\lambda}{a}$

Using this relation, estimate the wavelength, λ, of the red light.

5.3 (Experiment): To study the resolving power of a slit

Apparatus: Slit of uniform width (appendix 12), pattern of thick black lines, sodium lamp or table lamp covered with red cellophane.

Procedure: Make a pattern of 5 mm thick black lines 5 mm apart (Fig.5.3). Look at the

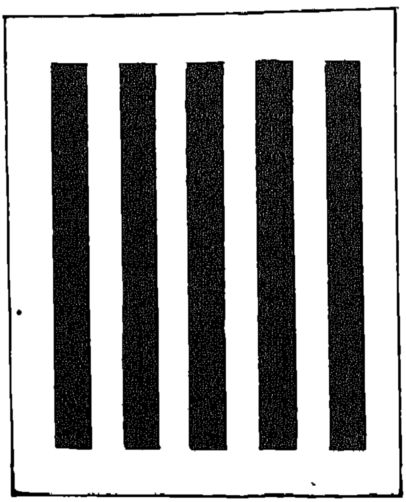

Fig 5.3

pattern illuminated by sodium light or red light. If you keep the slit perpendicular to lines, you see them sharp. However, if the slit is kept parallel to lines, the edges of the lines becomes blurred.

Keeping the slit parallel to the lines vary your distance from the pattern of lines till the lines merge into each other and you don't see them separate from each other. Measure this distance d. Also measure x the width or separation of the lines which are equal to each other. Then θ, the resolving angle of the slit is $\theta = \frac{x}{d}$

Since wave theory tells that resolving power of a slit is $\theta = \frac{\lambda}{a}$

Where λ is the wavelength of light and a is the width of slit, you can estimate λ if you measure a, as described in Experiment 5.2.

TOPIC 2 WAVE NATURE OF LIGHT

5.4 (Activity): To observe the diffraction pattern of a single slit and the effect of slit width on the pattern

Experiments 5.2 and 5 3 above illustrate that when a beam of light passes through a narrow region, the property of light to travel in straight lines breaks down and the beam spreads This phenomenon is called diffraction and is one of the evidence in favour of wave nature of light. Following simple activity will help you to understand this phenomenon a little more.

Hold two razor blades side by side (as shown in Fig.5.4), with their nearer sharp edges quite

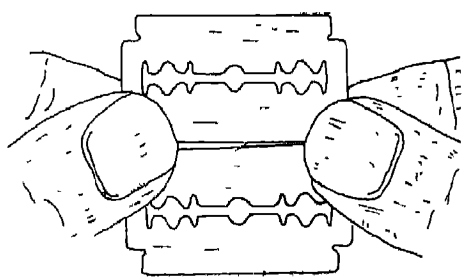

Fig. 5.4

close to each other. Observe a glowing clear electric lamp at sufficient distance (at least 10 m) through the slit between the two sharp edges. The lamp spreads into coloured fringes.

Observe through different parts of the slit, as the two edges are often not parallel to each other when held like this. Do you find that less the separation of edges, the wider are the fringes?

5.5 (Experiment): To estimate wavelength of red light/sodium light by Young's double slit

Apparatus: Double slit made on a microscope slide (appendix 13), a straight-filament lamp with red filter or sodium lamp in casing with narrow slit, metre scale, screw gauge/travelling microscope.

Procedure: Make the double slit alongwith a small window as described in appendix 13. Measure their separation, a, either by a travelling microscope or by measuring thickness of the blades by which this double slit was made.

Look through the double slit at the lamp, held at a distance of about 1 m. At the same distance as the lamp (either above it or below it) place the metre scale. You can clearly see the markings of the scale when you look through the window. When you look through the slits, you see the bright and dark fringes.

Observe on the scale, the position of the central fringe, four bright fringes to left of it and four bright fringes to the right of it. Record these 9 observations in the table and calculate 5 sets of values for 4 fringe widths (5th — 1st, 6th — 2nd, ...). Find the mean value of 4 fringe widths and then the width of one fringe x. Also measure the distance d from slit to the lamp.

Now path difference for two rays diffracted by slits A & B at an angle $\frac{x}{d}$ radian is λ and thus they re-inforce to give a bright fringe (Fig 5.5). If a is the separation of the two slits wavelength is:

$$\lambda = \frac{x\,a}{d}$$

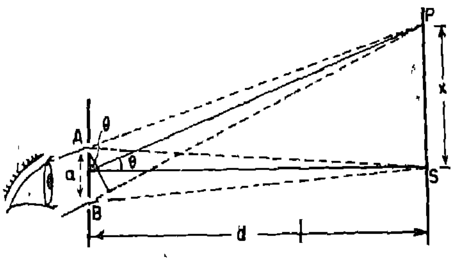

Fig. 5.5

You may find the wavelength using this relation.

Observations

Distance from slit to the lamp, d =

Separation of the slits, a = ____, ____, ____,

mean a = ____ mm

Fringe	*Position on scale*	*Width of 4 fringes*	*Mean width of 4 fringes*	*Width of one fringe, x*
4th left				
3rd left				
......	......	......	......	......
......	......	......	......	......
4th right				

$$\lambda = \frac{x\,a}{d} = \quad \text{nm}$$

Question: If your likely error in observing the position of the centre of a bright fringe on the scale is roughly 1/10th of a fringe width, then what is the likely percentage error in (i) any single value of width of four fringes, and (ii) width of one fringe calculated by you ?

5.6 (Activity): To estimate the wavelengths at the middle of seven spectrum colours as seen by your eyes, by using a diffraction grating.

Mount a small piece of low-cost diffraction grating G, in a frame and hold it with its grat-

ing lines vertical. Through it look at a line source of light S (with its filament parallel to lines of the grating) placed at a distance d (about 0.5 m) from the grating Perpendicular to the line joining the lamp and the grating, place a metre scale with its 50 cm mark just above or below the lamp (Fig. 5.6).

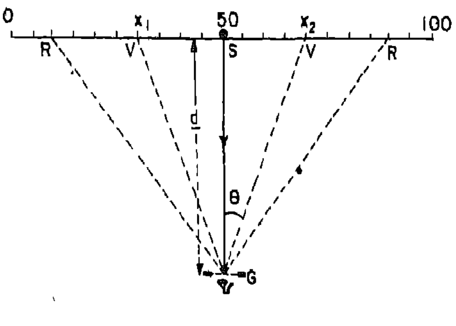

Fig. 5.6

Observe the first order spectrum of white light coming from the lamp. You observe it on the right as well as on the left of the lamp. You can also clearly see the mm-marks of the scale against both the spectra, through the diffraction grating, as the room is well-lit. Note the positions of mid-points of the seven colours in the scale for both the spectra. If x_1 and x_2 are these positions for a certain colour, then θ the angle of diffraction for this colour is

$$\theta = \tan^{-1} \frac{x_2 - x_1}{2d}$$

The wavelength corresponding to this angle of diffraction is $\lambda = a \sin \theta$,
where a is the spacing between adjacent lines of the grating and is known.

You can also use a spectrometer for this activity if you have it in your school and you can learn its use with the help of your teacher.

5.7 (Activity): The cloth grating

Look through a stretched piece of nylon cloth H at a distant lamp S, which is almost a point source of light due to its large distance (Fig. 5.7). You see a two-dimensional diffraction pattern, with various colours.

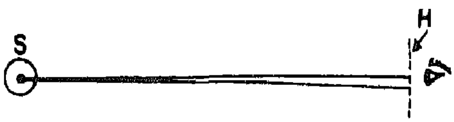

Fig 5 7

Rotate the piece of cloth in its own plane, and observe that the pattern rotates with it The two dimensional pattern is due to two sets of threads of the cloth perpendicular to each other. Each of the sets of threads, acts as diffraction grating.

5.8 (Demonstration): To demonstrate natural and plane polarized light by plastic polar sheets and its analogue by a stretched string

Stretch a string with one end held in your hand and the other tied to a fixed point, e.g. the door handle. Wave your hand randomly in all directions perpendicular to the string Transverse waves are observed to travel along the string. Any point of the string moves randomly in all directions in a plane perpendicular to the string. In like manner, common sources of light emit such light that at any point in space where its light is coming, the electric vector of the electromagnetic waves randomly takes up all possible directions in a plane perpendicular to light rays (as shown in Fig.10.9c in the textbook).

Next, wave your hand in a specific direction, say up and down. Now the waves travelling in the string are such that all points along the string

vibrate up and down. Motion of the entire string is confined to a plane, the vertical plane passing through it. We say the transverse waves in the string are plane polarised

The waves produced by your hand moving randomly in all directions perpendicular to the string can also be made plane polarised. Let the string pass through a vertical slit in which it can move with little friction. Then, only up and down component of motion of your hand passes through the slit, and waves between the slit and the fixed end are plane polarised (Fig. 5.8a). We

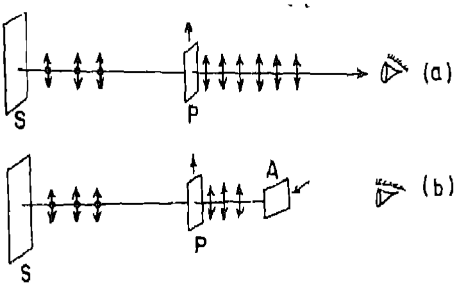

Fig. 5.9(a, b)

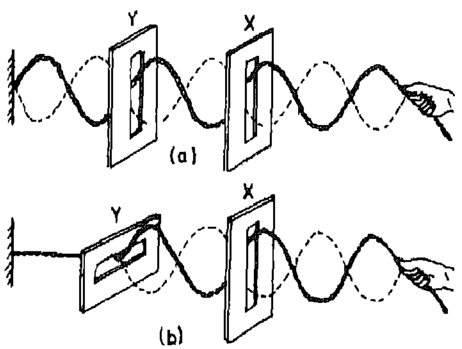

Fig. 5.8

may call this slit a *polariser*. If another vertical slit is introduced after the slit X it does not affect the plane polarisd waves. However, if the slit Y is horizontal, the vertical vibrations stop at it and no vibrations are transmitted (Fig.5.8b). Second slit may be called *analyser*, because the observation that no waves are transmitted through it is evidence that waves coming to it are polarised with vibrations perpendiclar to this slit.

Look at a white illuminated sheet, S through a plastic polaroid sheet, P (Fig.5.9a). You see it slightly dimmer because only half of the incident light energy is transmitted by the sheet. Rotate the plastic sheet in its own plane In this manner you change the direction of the axis of polarisation of the sheet, keeping it perpendicular to incident light. Observe that illuminance of the white surface seen through the sheet is not affected by so rotating it. Because the direction of electric vector in the light coming from the white surface is truely random in a plane perpendicular to your line of sight, time average of the component of electric vector in any particular direction (along which you make the axis of the polariser sheet), is the same The electric vector component perpendicular to axis of the polariser is absorbed by it. Since two mutually perpendicular components completely define a vector in a plane, the incident light energy is equally shared between these two mutually perpendicular components of the electric vector. Thus half of incident light energy is absorbed by the polariser which was the share of electric vector perpendicular to its axis.

Introduce another polaroid sheet, A, between the first one and your eye. You observe that when the axis of this polaroid is parallel to that of the first sheet, it transmits all the light. Thus the illuminance of the white surface that you see through it is not affected by it. However, on rotatig this polaroid in its own plane, when its axis is perpendicular to that of the first sheet, the white surface is not visible through it—all the light incident on it is absorbed (Fig.5.9b). This change in brightness of the white surface

that you observe through the various orientations of this polaroid, indicates that light incident on it is plane polarised The electric vector of this light is perpendicular to the axis of this polaroid in the orientation when it becomes opaque As the second polaroid enables us to analyse the polarisation of light passing through it, we call it an analyser

Note These observations using two plastic polaroid sheets are evidence that light consists of transverse waves, because the phenomenon of polarisation does not exist in longitudinal waves.

(2) A screen made of fine metal wires parallel to each other and with uniform mutual spacing of the order of a few microns, acts as a polaroid for infra-red radiation. The electric vector parallel to the wires produces electric currents in the wires Thus its energy is dissipated in the ohmic loses in the wires. Thus the electric vector perpendicular to the wires is transmitted, which is also the direction of the axis of this polariser. Such a polariser has been made in research laboratories, including the National Physical Laboratory, New Delhi.

(3) Plastic polaroid sheet consists of tiny microscopic needle-like crystals of an organic chemical such as idoquinine sulphate (herapathite) embedded in a plastic sheet. While making a polaroid, such a sheet is stretched greatly in one direction. Thus the needle-like crystals align them selves with their longer dimension in the direction in which the sheet is stretched. Thus it acquires the property of absorbing the component of electric vector in this direction. The crystals, being slightly conducting, act in the same manner as the wire elements of the wire screen polaroid mentioned in note (2) above.

5.9 (Demonstration): To demonstrate that when a beam of light reflects from a glass surface at Brewster angle, it becomes plane polarised.

Take a small glass plate which can be mounted on the optical disc to demonstrate reflection at a plane surface Its back side is ground and painted black, so that is partially reflects light from its front smooth surface only. Then this plate, M, is mounted in the centre of the optical disc (Fig.5.10).

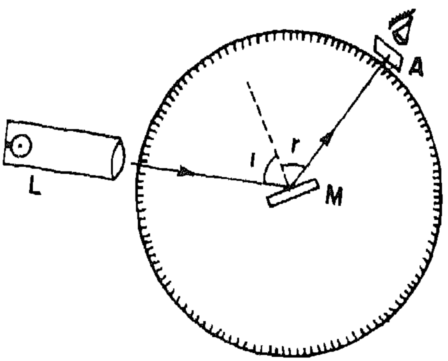

Fig. 5.10

A beam of light is allowed to fall on this 'mirror' at any angle of incidence. The reflected beam is seen passing along a radius of the disc due to its grazing incidence on the disc. Part of the reflected beam also escapes over the edge of disc, which is examined by an analyser A, (a plastic polaroid sheet). If the analyser can stop this beam in any particular orientation, then it is a beam of plane polarised light.

Try various angles of incidence, i, for the beam incident on the glass plate. You find that for a particular angle of incidence, the reflected beam becomes plane polarised with its electric vector parallel to axis of rotation of the optical disc. This angle of incidence is the Brewster angle.

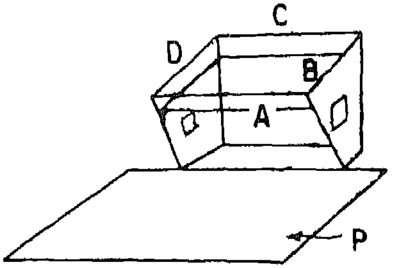

Fig 5.11

5.10 (Demonstration): To demonstrate polarisation of light by scattering.

Take a rectangular glass trough of the shape shown in Fig.5 11 Its front side,A, is inclined downwards at an angle between 20° and 30° to the vertical. The back C and sides B and D are painted black except for two small windows in B and D facing each other. A black paper, P is placed in front of it so that any stray light reflected from front side is reflected downwards and is absorbed by the black paper.

Fill clear filtered water in the trough and cover an opaque lid on it Using the beam lamp of the optical disc, focus a beam of light at the centre of the trough through one of the side windows You observe the beam through the unpained front glass, as water scatters a very small fraction of the energy in the beam of light Because of efficient arrangement in this apparatus to provide a black background you can observe the beam, though scattering of light by water is very small. If just one drop of fresh milk is added to water, the scattering increases and you see the beam quite bright

Observe the beam through a plastic polaroid sheet. When the axis of the polaroid sheet is horizontal you do not see the beam though you see all the rest of the apparatus. This shows that scattered light reaching the observers in front of the unpainted glass of the trough, is plane polarised with its electric vector in a vertical plane.

TOPIC 3· PHOTOMETRY

5.11 (Experiment) To compare the luminous intensities of two lamps, say one of 40W and the other of 100W.

Apparatus: Two electric lamps of 40W and 100W of the same company, Bunsen's grease spot photometer, metre scale, multimeter, 4Ω and 10Ω resistors.

Procedure: Take lamps of 40W and 100W of the same company, because two lamps of same voltage and wattage rating made by different companies, may differ considerably in the amount of light they give.

Put one lamp S_1, say the 100W lamp, on one side of the photometer P at distance d_1. Put the other lamp S_2 on the other side of the photometer and adjust its distance, d_2 such that the greese spot G appears as bright as its surrounding portion R when seen from any of the two sides (Fig.5.12). At this adjustment, illum-

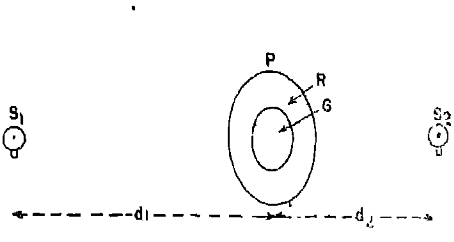

Fig. 5.12

inance produced by the two lamps at the photometer are equal. You must work in a room which can be darkened by switching off other lights while this adjustment is done. Measure d_1, and d_2

Next put the first lamp at same distance d_1 on the other side of the photometer and second lamp on the first side. Again adjust d_2 so that illuminance produced by the two lamps are equal. This value of d_2 may differ from the first because (i) there may be some stray illuminance on the photometer which may not be

equal on both the sides since you are not working in a photographic dark room; (ii) there may be unequal reflection of light of the lamps under investigation by walls of the room on the two sides of the photometer. Measure both d_1 and d_2 in the adjustment too. Record the four observations in the table given here and find mean values of d_1 and d_2. Then

$$\frac{I_1}{I_2} = \frac{d_1^2}{d_2}$$

For energising the two lamps make electrical circuit as shown in figure 5.13, so that a small 10Ω resistor is in series with 40W lamp and 4Ω in series with 100W lamp. Measure voltage across each resistor and thus find the current, i_1 and i_2 passing in the two lamps. Also measure voltages V_1 and V_2 across the two lamps. Thus find the electric power fed into each lamp. Ratio of the efficiencies of the two lamps is

$$\frac{I_1}{V_1 i_1} + \frac{I_2}{V_2 i_2} = \frac{I_1}{I_2} \frac{V_2 i_2}{V_1 i_1},$$

which may now be calculated.

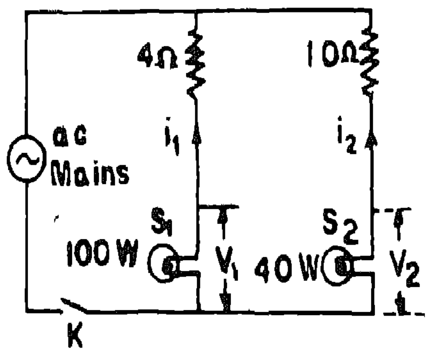

Fig. 5.13

Observations

Voltage across 100W lamp, V_1 =
" " 40W , V_2 =
Current through 100W lamp, i_1 =
" " 40W lamp, i_2 =

S.No.	100W lamp on left		100W lamp on right		Mean		$\frac{I_1}{I_2} = \frac{d_1^2}{d_2^2\,(cm)}$
	d_1 (cm)	d_2 (cm)	d_1 (cm)	d_2 (cm)	d_1 (cm)	d_2 (cm)	

Mean Value of $\frac{I_1}{I_2} =$

$\frac{\text{Efficiency of 100W lamp}}{\text{Efficiency of 40 W lamp.}} = \frac{I_1}{I_2} \; \frac{V_2 i_2}{V_1 i_1} =$

Note: Generally the lamp of a higher power rating tends to be more efficient Working at the same voltage, it takes up more current, has a thicker filament and operates at a higher temperature. Hence greater portion of its energy consumed is converted to visible light and its light is also 'whiter'

Exercise: You have a 6 volt 24 watt lamp and another 220 volt 25 watt lamp. Which one you expect to be more efficient? Check up your guess by actual experimentation, using the above method.

TOPIC IV · REFRACTION OF LIGHT AT PLANE SURFACES

5.12 (E) : To study the relation between angle of incidence and angle of refraction, using a rectangular glass slab.

Apparatus : Drawing board, drawing paper, pins, glass slab, protector, ruler, drawing pins and sharp pencil.

Procedure: Fasten the paper on the drawing board by four drawing pins. Place the glass slab in the centre of paper and mark its boundary

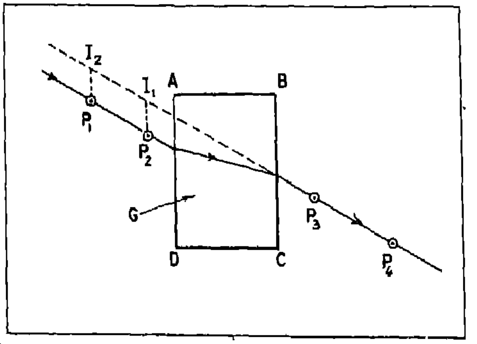

Fig 5 14

ABCD (Fig.5.14). Place two pins P_1 and P_2 opposite a longer side of the slab. Look through the side BC of the slab and observe the images of pins P_1 and P_2. Place two more pins P_3 and P_4 so that they appear to be in line with the images I_1, and I_2 of pins P_1 and P_2. Look from the side of pin P_1 as well and check up that on this side too the four pins appear to be collinear The four pins represent the path along which a ray of light would pass through the slab, from P_1 to P_4 as well as from P_4 to P_1.

Remove the pins and mark their positions Remove the slab and draw the path of the ray of light on the paper. Draw normals on surfaces AD and BC at points where this ray of light meets these surfaces Measure both angles of

Observation

S.No.	Side AD		Side BC		Mean		Sin i	Sin r
	i	r	i	r	i	r		

From the graph, slope n_g =

incidence and corresponding angles of refraction. Since both the angles of incidence are expected to be equal, find mean i and mean r Repeat the experiment with various angles of incidence in the range 0° to 80° and enter the observations in the table. (p. 161)

Draw a graph between i and r taking the angle r along the X-axis. Also draw a graph between $\sin i$ and $\sin r$, taking $\sin r$ along X-axis. Which of the two graphs is a straight line? Find the slop of straight line graph, which gives the refractive index of glass, n_g

Note: While fixing the pins P_1, P_2, P_3 and P_4 it is inevitable that these will not be accurately perpendicular to drawing paper. Thus if their feet are collinear, their heads may not be collinear. When you mark of the position of a pin on paper, you take the pin hole made by it, which is the position of its foot. Hence, while observing that the pins are collinear, you must ensure that their feet are collinear.

(2) For large angle of incidence, say about 70° or 80°, it is likely that images I_1 and I_2 may show some colours, because refractive index of glass is greater for voilet colour and less for red. If it happens, look through a yellow filter to cut off other colours. Then make P_3 and P_4 collinear with yellow images I_1 and I_2.

5.13 (Activity): To study the relation between angle of incidence of a ray of light inside glass slab and angle of refraction in air and find the critical angle.

Use the same arrangement as in experiment 5.12 above. Pin P_1 is not needed and put pin P_2 in contact with the glass (Fig.5.14). Still better is to make a small rectangle of paper whose length is equal to height of the glass slab. Draw a line length-wise in its centre with a red ball-point pen. Stick this paper on the side AD by gum (or temporarily by glycerol) about 1/8th

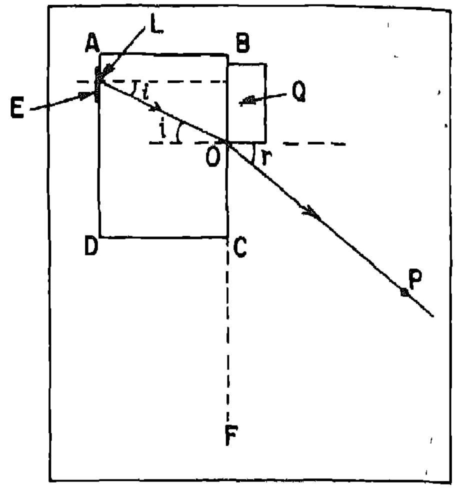

Fig. 5.15

of the way from A to D (Fig.5 15), so that the line L is vertical.

For indentifying a ray, AO inside the slab, put a wooden block with sharp edges or an aluminium angle Q against the face BC of the slab, so that its vertical edge O is in contact with BC. Fix a pin P such that P,O and L *appear* to be collinear. Then LOP represents the path along which a ray of light would pass from L to P Remove the slab, Draw lines LO and OP and the normal at O. Measure angles i and r and find $\sin i$ and $\sin r$.

Repeat the experiment for various position of point O along BC As you take position of O closer to C, positions of pin P come closer to line B C F. Ultimately you will find a position, where the line L can not be seen, as the ray LO gets totally reflected inside the slab. Mark the position of O where the line L just cannot be seen. Angle of incidence at the position is the critical angle i_c (strictly speaking for red colour). Do you find that $\frac{\sin i}{\sin r}$ is constant and equals $\sin i_c$? What does this constant ratio represent?

Exercise: Referring to figure 5.15, you stick the paper E by a drop of glycerol. Now you look at the line L through the side CD of the slab, put the wooden block or aluminium angle Q along the side CD of the slab and try positions of its edge O successively closer to D. Then you will find a position of the aluminium angle Q in which the line L is not visible. In that position what does the angle contained between line LO and the normal at L represent?

5.14 (Demonstration): Demonstration of total internal reflection by an aircell

Suspend an air cell A made between two glass plates PP into a transparent liquid filled in a rectangular glass vessel B (Fig.5.16). Let the cell

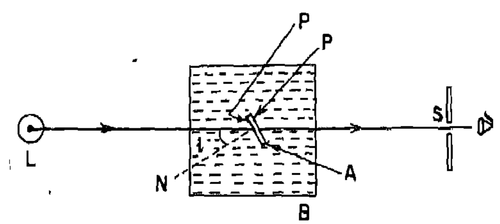

Fig. 5.16

be approximately in the centre of the boundary of the vessel. On one side of the vessel is a torch bulb L (almost a point source of light) and it is viewed through a slit S on the other side of the vessel. The ray of light that you see passes through the liquid and the air cell. When the cell is normal to this ray you see the bulb in full brightness. Now slowly rotate the air cell by the rod by which it is suspended keeping it always vertical, so that normal to the mirror makes a gradually increasing angle of incidence, *i* with the ray of light. Observe that gradually the bulb as seen through slit S becomes dim. A stage comes when it appears very dim and red. On rotating the air cell a little more, bulb is not at all seen and the air cell appears to be like a mirror. The angle of incidence at this stage is the critical angle.

Note: (1) Standard apparatus is available by which this angle can also be measured quite accurately for any liquid in the beaker. If that apparatus is available, this experiment can also be performed by students in the laboratory.

(2) For demonstration to a whole class, let a strong beam of light fall on the air cell instead of the torch bulb giving a dim ray of light. Receive the ray passing through the S on a white screen at 45° to the ray of light.

5.15 (Activity): To study the relation between real depth and apparent depth of a transparent medium.

Put a glass slab on a white sheet on which a line L is drawn One vertical side S of the slab is adjusted to be perpendicular to this line, i.e. coinciding a line drawn on paper perpendicular to L. Hold a fine sewing needle N in a stand touching this vertical side (Fig.5 17). Remove

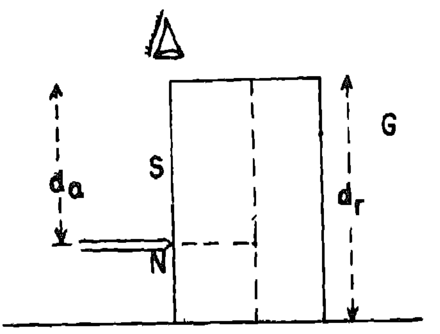

Fig. 5.17

parallax between virtual image of the portion line L inside the slab and tip of the needle outside the slab. Measure height d_r of the slab, which is the real depth of the transparent medium. Measure height of the needle above the paper, which is the apparent rise of the bottom of the transparent medium Difference

of the two measurements gives the apprarent depth d_a of the transparent medium. Do this experiment for all the three dimensions of the slab kept vertical turn by turn? Find the ratio $\frac{\text{real depth}}{\text{apparent depth}}$ in each case

If a travelling microscope is available and you know how to use it, you can make these measurements with much precision You can also work with any liquid filled in a beaker. Bottom may be marked by sticking a piece of paper (with a mark on it) at the bottom of the beaker, using a transparent adhesive tape to cover it. Surface of liquid may be marked by dusting a little lycopodium powder on it. Note readings of microscope in position a, b and c (Fig 5.18) corresponding to bottom of empty

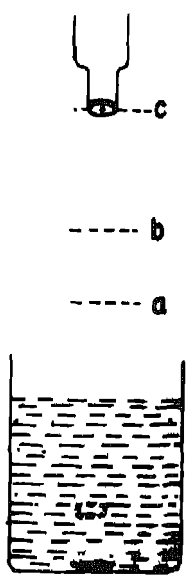

Fig. 5.18

beaker, bottom as seen with liquid filled in it and surface of liquid. Thus find $\frac{\text{real depth}}{\text{apparent depth}}$.

5.16 (Experiment): To study the variation of angle of deviation of a ray of light passing through a prism with angle of incidence and find the refractive index of the medium of the prism.

Apparatus: Drawing board, white paper, pins, prism.

Procedure: Fix a sheet of a white paper in the drawing board. Mark a line AB. At a point E. on this line draw normal NE and an incident ray DE at any desired angle of incidence i (Fig.5.19). Do not keep i less than 30°, as the

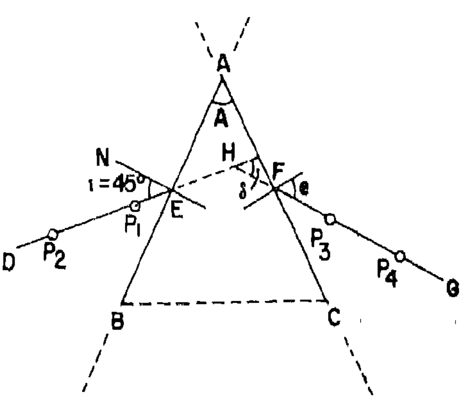

Fig. 5.19

ray may get totally reflected inside the prism. By keeping a ruler along the line AB, place the prism along the ruler, so that one refracting face of the prism accurately coincides with the line AB. Refracting edge A of the prism should be vertical.

Fix two pins P_1 and P_2 on the incident ray already marked. Looking into the prism from the opposite refracting surface, AC, position one eye, by which you are seeing, such that feet of P_1 and P_2 appear to be one behind the other. Now fix pins P_3 and P_4 in line with P_1 and P_2 as viewed through the prism. Keep your eye at some distance from the pins so that all of them

can be seen in clear focus simultaneously. Distance $P_1 P_2$ and $P_3 P_4$ should not be less than 6 cm so that you can locate the directions of incident ray DE and emergent ray FG with an accuracy of the order of 1°

Remove the pins. Put a scale along side AC, remove the prism and then draw a long line representing the refracting surface AC Mark the position of the pins. Draw line joining P_3 and P_4. Produce lines $P_2 P_1$ and $P_4 P_3$ so that they intersect at H. Measure the angle of incidence i (angle DEN), angle of deviation δ and angle of the prism A. Repeat the experiment for several angles of incidence between 30° and 60° at intervals of about 5°. Enter the results in table given below.

Plot a graph between i and δ, keeping δ along y-axis. From the U-shaped graph, find minimum diviation δ_m. Calculate the refractive index of the material of the prism using the relations:

$$n = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin \frac{A}{2}}$$

Observations

S.No	*Angle of incidence, i*	*Angle of deviation, δ*	Angle of the Prism, A

From the graph, δ_m=
Refractive index of glass of the prism=

Note: In this experiment there is no use of drawing the boundary of the prism Common prism are quite small, a triangle of about 2.5 cm or 3 cm sides. With such small lines angle i or A cannot be accurately measured. Hence in above procedure, we draw a long line for faces AB and AC with a ruler and place the prism touching the ruler.

5.17 (Experiment): To find the refractive index of (a) the material of a prism and (b) a liquid, by using a hollow prism, for sodium light or yellow colour.

Apparatus: Spectrometer, prism, sodium lamp, automobile lamp, a lens to focus the image of light source on slit of the spectrometer.

The Spectrometer: Following are the main parts of Spectrometer, which are shown in Fig 5.20:

(i) *Collimator C*. It consists of a tube with an achromatic lens at one end and an adjustible slit at the other (Fig 5.20). An image of light source L is focussed on the slit. Light entering the slit becomes a parallel beam, by the lens.

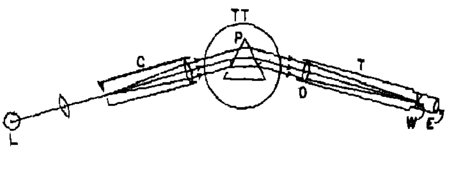

Fig. 5.20

(ii) *Turn table TT:* On the turn table we fix the prism (or any optical device under study) which produces deviation and dispersion in the beam of light coming from the collimator. It can rotate about a vertical axis to orient the prism as desired.

(iii) *Telescope T*: It receives the deviated light from the prism. It is provided with an eye-piece E fitted with cross-wires W.

The optical axis of collimator and telescope meet on the axis of rotation of the table. The telescope is also capable of rotation about the same axis

In order to adjust the sepectometer, first adjust the eye-piece of the telescope until the cross-wires can be seen quite clearly and without strain. Next, turn the telescope towards a distant object seen through an open window. Adjust the focussing screw which alters the mutual distance between eye piece and objective. The adjustment is alright when there is no parallax between the image of distant object and the cross-wires. The telescope is now focused to receive parallel light. Now illuminate the slit of the collimator. Turn the telescope into line with the collimator and view the slit by light which passes through both collimator and telescope. Adjust collimator screw until the image of the slit is clearly seen with no parallax between it and cross-wires. The collimator is now adjusted to provide a parallel beam of light.

Now fix the prism on the turn table The table is provided with three levelling screws P, Q and R (Fig.5.21). The prism must be so fixed that

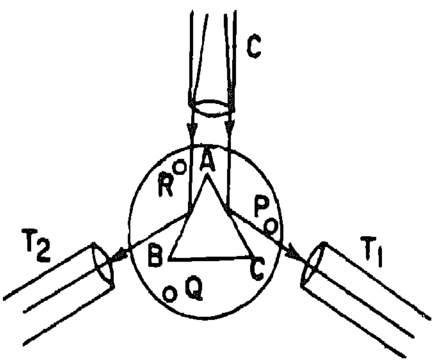

Fig. 5.21

one of the faces AC bounding the refracting edge A, is perpendicular to the line joining two screws P and Q The table has to be so levelled that the edge A is parallel to the axis of the spectrometer.

Rotate the table TT, such that the refracting edge A faces the collimator. Thus half of the light from the collimator falls on face AB and half on face AC. Turn the telescope to position T_1 to receive light reflected from face AC Adjust the plane of face AC by screw P or Q till centre of the image of slit coincides with the centre of the cross-wires. Now turn the telescope to position T_2 to receive light reflected from face AB. Adjust the screw R (in order to adjust the plane of face AB without disturbing the plane of face AC) until centre of the image of slit again coincides with the centre of the cross wires. By bringing telescope in position T_1 check up that the face AC has not been disturbed by adjustment of screw R. If it has been disturbed, repeat the process.

Angle between the positions T_1 and T_2 of the telescope (Fig.5.21) is 2*A*. Observe the readings on the circular scale θ_1 and θ_2 corresponding to these positions. Then angle of the prism is:

$$A = \frac{1}{2} (\theta_1 - \theta_1)$$

To measure the angle of minimum deviation, turn the table so that light of collimator falls on one refracting face, say AC and emerges from the other, deviating towards the right. Rotate the telescope so that it receives the emergent beam. Adjust orientation of prism by rotating the table so that deviation is minimum and then adjust telescope so that image of the slit coincides with centre of the cross-wires. Note this position of the telescope ϕ_1 on the circular scale of the spectrometer. Next, let the light of collimator fall on refracting face AB so that deviation is towards the left. Repeat the above process and note the position ϕ_2 of telescope for minimum deviation towards the left. Between these two positions telescope rotates through twice the angle of minimum deviation, i.e. 2 δ_m. Thus calculate δ_m:

$$\delta_m = \frac{1}{2} (\phi_1 - \phi_2)$$

Knowing the values of *A* and δ_m you can now calculate the refractive index of the mater-

ial of the prism.

$$n_g = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin \frac{A}{2}}$$

For the experiment (b), i e. measuring refractive index of a liquid, replace glass prism by a hollow prism full of that liquid on the turn table of the spectrometer. Adjust its refracting edge parallel to axis of the spectromter. Then measure A and δ_m for this prism by exactly same procedure as described above and calculate refractive index of the liquid.

Note: 1. In case the slit is illuminated by sodium light, which is almost a monochromatic light (i e. entire light energy in the beam is of a single wavelength), then in the position of minimum deviation, you will observe a single image of the slit in the telescope You have to adjust telescope so that it coincides with the centre of cross-wires, and there is no ambiguity.

2. In case the slit is illuminated by light of an electric lamp, then you see a spectrum containing seven colours in the deviated beam. To find the refractive index of the material of the prism for visible light, you should adjust minimum deviation position of the prism for yellow colour and measure it by bringing the centre of yellow band at the centre of cross-wires. Thus you measure refractive index for yellow colour.

5.18 (Activity): To observe the spectrum of white light through a prism and estimate its dispersion.

By using the spectrometer you can use the method explained in note(2) of the previous experiment above, to find refractive indices for blue colour and red colour and then find their difference. It is not an accurate and clear cut measurement, because you see a continuous spectrum. Judgement of centre of blue band, for example, is only a rough judgement which also differs from person to person. Suppose one person sets the crosswire of telescope close to green in the blue band. Then there may be another person who sees the same light rays reaching the cross-wires as green telling that cross-wire are in green band close to blue Due to this "roughness" in this experiment, you may adjust the prism in minimum deviation position for yellow only. Then measure diviations for both, the red and blue colours and calculate n_b and n_r. Then calculate the dispersive power, ω ·

$$\omega = \frac{n_b - n_r}{\frac{1}{2}(n_b + n_r) - 1}$$

Without the spectrometer, you may use the improvised arrangement described in activity 5 6 for the diffraction grating experiment. In place of grating put the prism. Adjust it first for minimum deviation to the right and observe readings x_1 and y_1, on the metre scale for the red and blue bands, (respectively. You cannot see the marks of the scale against the spectrum through the prism. The best way is to position one eye to see the metre scale just above the prism and the spectrum through the prism coinciding with its lower edge. Repeat the experiment for deviation to the left and observe readings x_2 and y_2 on the scale for red and blue bands. Then, if d is the perpendicular distance from centre of the prism to the metre scale,

Min deviation for red, $\delta_r = \tan^{-1} \frac{x_2 - x_1}{2\,d}$

Min deviation for blue $\delta_r = \tan^{-1} \frac{y_2 - y_1}{2\,d}$

The prism used in school laboratories is commonly of angle 60°, being an equilateral triangular prism. Thus calculate n_b and n_r assuming $A = 60°$.

Note: You may find that the 6 V, 24 W auto-

mobile bulb is too bright and the spectrum seen through the prism causes glare, though it was alright for the diffraction grating. Hence, it is advisible to use a torch bulb to see the spectrum through the prism. Another good alternative is to fix a new, brightly nickel-plated pin and illuminate it by a beam of light.

TOPIC V · SPHERICAL MIRRORS AND LENSES

Optical bench·

An optical bench consists essentially of a long horizontal beam (of seasoned wood or metal) provided with sliding carriages, called *uprights*, for holding lenses, mirrors, pins, screen, candle wire gauze, etc Location of an optical element mounted on an upright is read on a scale attached to the bench by a mark made at the base of the upright. The optical bench basically helps to set up an axis along which are kept the important points of the experimental set up e.g. pole of the mirror, optical centre of the lens, tip of the object pin, etc.

Usually the distance between concerned points of two elements is not the same as the distance between their uprights as read on the scale. For example, in Fig.5.22, the readings of

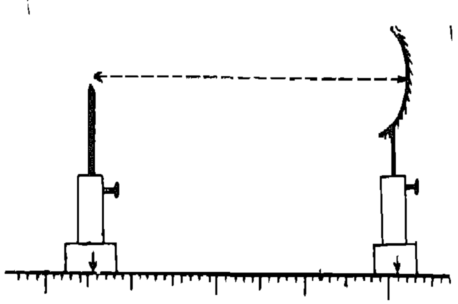

Fig. 5.22

two uprights do not give the actual distance between the tip of the pin and the pole of the mirror. A correction must, therefore, be applied. It is called the *index correction*. To find this correction, a thin straight needle is so placed so that its one end touches the tip of the pin and the other end touches the pole of the mirror The positions of the uprights are read on the scale and their difference gives the observed distance. Length of the needle is also measured by placing it on the scale, which is the actual distance. The difference between the two gives the correction to be applied in observed distance to obtain the actual distance.

Following general instructions are important to follow in all experiments with optical bench.

(i) Optical axis of the elements under study must be parallel to the bench. The mirrors, lenses, pins, screens, all should be in planes at right angles to this axis. The heights of the uprights should be so adjusted that the tips of the pins, poles of mirrors, optical centres of lenses all lie on this axis.

(ii) In an experiment with a converging mirror or lens, a knowledge of its rough focal length is useful. It can be found by obtaining a sharp image of a distant object on a plane wall, or sheet of paper, or just on your palm and measuring the distance roughtly with a scale A distant window or tree can serve the purpose well.

(iii) Use a brightly polished pin as object. If necessary, illuminate it from the side to get a reasonably bright image. Putting a white screen as background also helps. At times you may want to make measurement for light of a certain colour, e g. red or blue, etc Then you can paint the object pin with that poster colour, or put a screen of that colour as background.

(iv) Sometimes two pins, one for the object and other for locating the image may confuse a student. Put a small piece of white paper on one of them to differentiate one from the other.

(v) When magnification is large and the image is thick, it is helpful to use a thin pin as object and a thicker one for locating the image position. Similarly, when image is very small, use a thick pin as object and a thin one for locat-

ing the image

(vi) It is helpful to first make an approximate idea of the location of image using a pencil held in hand If it is off the axis of the experimental set up, this approximate location helps to make necessary adjustments. Then accurately locate the image with a pin mounted on an upright.

(vii) An object point O and its real image I are conjugate points, i.e. any of the two may be considered as object and the other is its image (Fig.,5.23). Thus, it helps in accurate

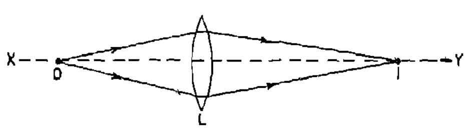

Fig 5.23

adjustment to check up for no parallax at both the points. When we say there is no parallax between a pin P and an image I, we move the eye by which we are observing to left and right Then both appear to move together relative to the lens/mirror. It implies that positions of both are same on the optical bench. If their positions are not same then in one position they may appear to concide and in another they will appear separate (Fig. 5 24 a,b) This method of locating the position of an image on the optical bench by a pin is called *method of parallax*

5.19 (Experiment): To find the focal length of a concave mirror, (a) by locating the centre of curvature (b) by graphical method.

Apparatus: Optical bench with two mounted pins, concave mirror and upright for it, index needle.

Procedure: (a) *By locating centre of curvature*: Obtain a rough value of its focal length by focussing the image of a distant object. Twice of this focal length is an approximate values of radius of curvature of the mirror. Place a mounted pin at this distance (radius of curvature) in front of the concave mirror. See the image of the pin and make adjustments to make tip of the image, tip of the object and centre of mirror to be in a straight line. To achieve this it may be necessary to tilt the mirror slightly and adjust height of the pin or mirror.

Adjust position of the pin until it coincides with its real inverted image made by the mirror (fig.5.25) This is checked by method of parallax. Make final adjustments as mentioned above so that tips of the image and object coincide

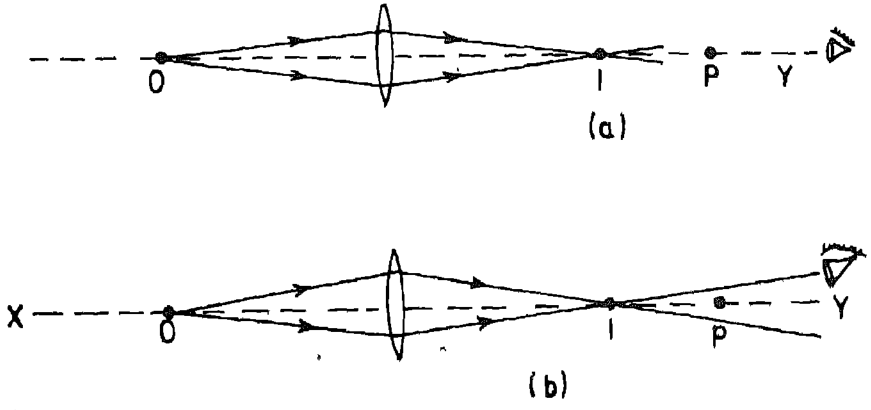

Fig. 5.24

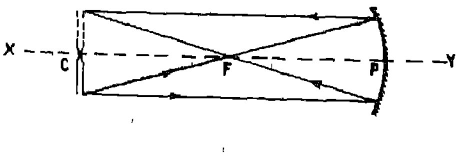

Fig. 5.25

accurately. Measure the distance of the pin from the pole of the mirror. Repeat three or four times, preferably at different places on the optical bench. This avoids the possibility that a fore-knowledge of the first position of the pin may bias the second and later readings. Take the mean of these readings to obtain the radius of curvature, R. Half of this is the focal length, f

Observations: Actual length of index needle =
Observed length of index needle =
Index correction =

S.No.	Position of pin (cm)	Position of mirror (cm)	Observed R (cm)	Mean Observed R (cm)	Corrected R (cm)

(a) *By Graphical Method*

Obtain a rough value of focal length of the mirror. Then mount the mirror and two pins in front of it on the optical bench keeping the pins close to centre of curvature. Distance of one pin is less then R and that of other is more than R. Make adjustments to make the five points, vis. tips of the two pins and their images and pole of the mirror, lie in a straight line parallel to the optical bench. Adjust positions of the pins, using parallax method so that image of one pin

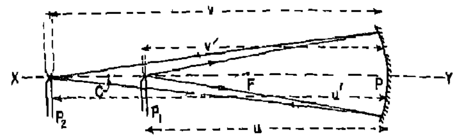

Fig 5.26

coincides with the second and image of the second pin coincides with the first (Fig. 5.26).

Measure the distance of each pin from the pole of the mirror. Each of these distance is one value of object distance, u, and the other distance is corresponding value of image distance, v.

Move the closer pin a little close to the mirror and repeat the experiment. In this manner take three or four sets of observations.

Plot a graph of values of u against corresponding values of v. Take the values as positive for plotting the graph though according to sign convention u and v are negative in this experiment. Since all the values of u and v are greater than focal length, you may take the origin to represent a value close to rough focal length on both the axes and thus choose a larger scale for the graph. You get a curve, which gives you a clear picture of how u changes with v. You get a straight line, if you plot a graph of $\frac{1}{u}$ against $\frac{1}{v}$. Draw the best straight line through the points and produce it to intersect both the axes, (Fig.5.27). Each intercept, OA on X-axis and OB on Y-axis, give a value for $\frac{1}{f}$.

Observations: Actual length of index needle =
Observed length of index needle on pin P_1=
Observed length of index needle on pin P_2=
Index correction for pin P_1=
Index correction for pin P_2=

S.No	Position of P_1 (cm)	Position of P_2 (cm)	Position of mirror (cm)	Observed u (cm)	Observed v (cm)	Corrected u (cm)	Corrected v (cm)	$\frac{1}{u}$	$\frac{1}{v}$

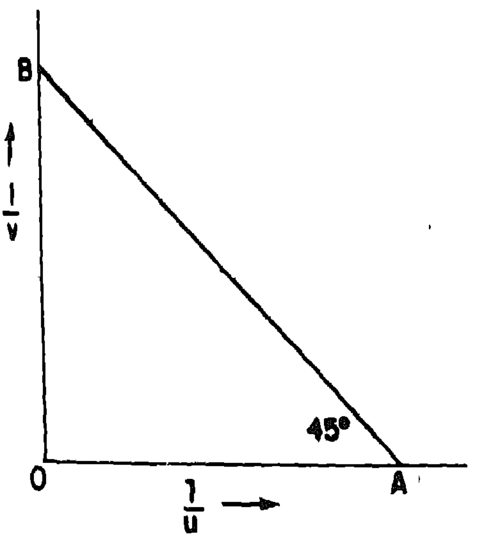

Fig. 5.27

From the graph OA = _____ cm^{-1},
i.e. f = _______ cm
OB = _______ cm^{-1}
i.e. f = _______ cm

Mean f = _____cm.

Note: 1. Do not place the closer pin closer than the focal length of the mirror, because it will produce a virtual image. It is helpful to mark with a chalk on the optical bench approximate positions of focus F and centre of curvature C.
2. Pay special attention to the method of interchanging the values of u and v, thereby obtaining two points on the graph from one pair of readings.

5.20 (Experiment): To find the focal length of a convex lens by graphical method.

Apparatus : Optical bench with two mounted pins, convex lens and upright for it, index needle.

Procedure: Obtain a rough value for the focal length of the lens by focussing the image of a distant object on a sheet of paper.

Place an object pin at a distance from the lens equal to $2f$ and locate the position of the real image on the other side of the lens by the image pin, by the method of parallax. Since the image and object are interchangeable, as in case of a concave mirror (experiment 5.19), check up for no parallax at both the pins (Fig.5.28). Measure the distance of the object pin, u, and of the image pin v from the lens.

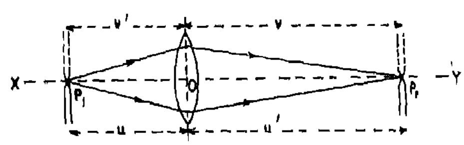

Fig. 5.28

Now move the object pin about 2 cm nearer the lens and locate the new position of the image. Moving the object pin nearer to the lens each time, take at least three or four such pair of readings.

Not forgetting that the two readings of each pair are interchangeable (conjugate points), plot a graph of u against v and another graph of $\frac{1}{v}$ against $\frac{1}{u}$. The latter graph is a straight line. Although u is negative and v is positive in this experiment according to the convention of signs, take positive values of each for plotting the graphs. Draw the best straigth line through the point plotted for the $\frac{1}{u}$ vs $\frac{1}{v}$ graph and produce it to intersect both axes, (Fig. 5.27) Each intercept, OA on X-axis and OB on y-axis, gives a value for $\frac{1}{f}$.

Observations: Same table as that for the experiment 5.19 with concave mirror

Note: 1 As u changes from 2 f to f, v changes from 2 f to infinity. Remembering that the values of u and v are interchangeable, it is clear that complete range of values for both u and v between f and infinity are obtained for a movement of the object pin over the range 2 f to f.

2. As in case of concave mirror, it is usless to place the object pin nearer to the lens than the focal length, as the image produced would be virtual.

3. If you are using a double convex lens, both faces having equal radius of curvature, then increase the index correction for both pins P_1 & P_2 (Fig.5.28) by half the thickness of the lens. Then corrected distances of the pins will be obtained from the optical centre, O, of the lens.

5.21 (Experiment): To determine the radii of curvature of the surfaces of a convex lens and thus the refractive index of the material of the lens.

Apparatus: Spherometer, glass slab, convex lens whose focal length f is known. It may be same lens whose focal length was measured in experiment 5.20.

Procedure: Find out how far the screw of the spherometer advances, as measured on the vartical scale V (Fig 5.29), when rotated through

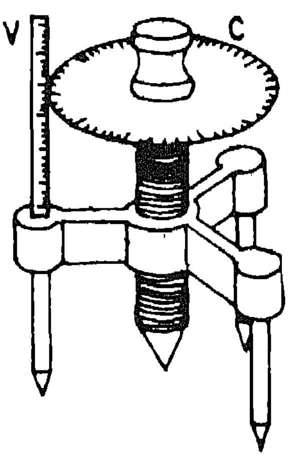

Fig. 5.29

one revolution of the circular scale C. This is usually 0.5 mm or 1.0 mm. Thus find the least count, i.e. how far the screw advances when rotated through one division on the circular scale.

Now place the spherometer on the glass slab. Screw down the central leg until its tip touches the glass surface. In this position the zeros of the two scales should coincide but usually it may not. Hence read the circular scale. Repeat the observation three or four times. Record all the zoro readings and find their mean.

Now screw up the middle leg, place the spheromoter with its three outer legs on one

curved surface of the lens Then screw down the middle leg until it just touches the curved surface and read the two scales Repeat this observation three or four times. Record all the readings and find their mean. Difference of this reading and zero reading gives the bulge, h_1 of the curved surface (or depression in case of a concave surface). Repeat this experiment for the other curved surface of lens and thus find its bulge, h_2.

Measure the distances between each pair of the three outer legs and take the mean, l, of the three readings. These measurements may be taken either by putting a scale straight across the points of the legs, or by measuring the distances between the indentations produced when the instrument is pressed on a piece of paper. Then calculate radius of curvature of first surface R_1:

$$R_1 = \frac{l^2}{6h_1} + \frac{h_1}{2}$$

Similarly calculate radius of curvature of second surface, R_2. Then find n, the refractive index of the material of the lens using the relation:

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

It may be recalled here that, according to the convention of signs, R_1 is positive and R_2 is negative in case of a double convex lens (Fig. 5.30).

Observations

Zero reading. ___, ___, ___ Mean = ± ___ mm

Reading of h_1 ___, ___, ___, Mean = ___ mm

Reading of h_2 ___, ___, ___, Mean = ___ mm

$\therefore$ h_1= ____ mm, h_2 = ____ mm,

Reading of l: ___, ___, ___, Mean= ___ mm.

$\therefore R_1$ = __________ mm.

and R_2 = __________ mm.

Notes. 1. In regard to ensuring when the tip of the central leg just touches the glass surface, one popular opinion is to observe the gap between this tip and its image formed by reflection in the glass surface. When its gap is not visible, the tip of the central leg is assumed to touch the glass surface However, on doing so you may find that the central leg can still advance down by several divisions of the circular scale. If the least count is say, 005 mm, then a gap of several least counts will not be visible. Hence a better method is as under. If this leg is screwed down too far the instrument will 'wobble' or 'rock', since the outer three legs will be lifted up. The correct adjustment is the point where the spherometer will not rock, but will do so if the screw is turned through another small division of the circular scale

2. The last movement of the screw before a reading is taken should always be in the direction of downward movement through the nut.

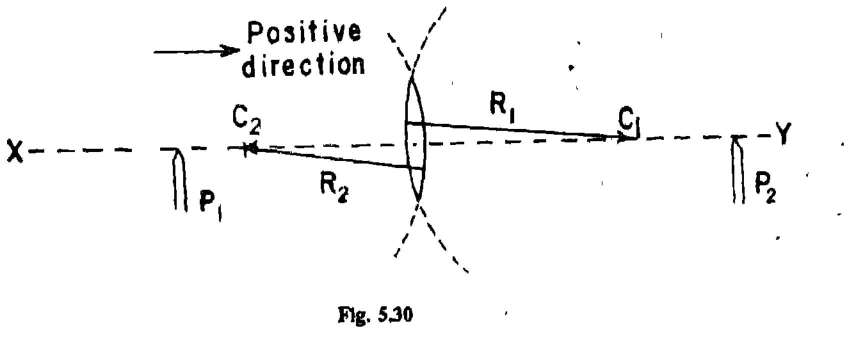

Fig. 5.30

This precaution eliminates the back-lash error

5.22 (Experiment): To determine the focal length of a convex mirror using a convex lens.

Apparatus: Optical bench with two pins, a convex lens and a convex mirror with their uprights, index needle.

Procedure: Place a mounted pin P_1 at a distance from the convex lens greater than its focal length. Locate its real inverted image on the other side of the lens by removing parallax between the image and second pin P_2 (Fig.5.31).

Place the convex mirror between pin P_2 and the lens. Adjust the position of the mirror till the light rays reflected back from the mirror pass through the lens and form an image coinciding with the pin P_1 (Fig. 5.31). This occurs when the rays of light starting from tip of P_1, after passing through the lens strike the mirror normally and are reflected back along their original paths. When this adjustment has been made, measure the distance between mirror and pin P_2, which is radius of curvature R of the mirror. The focal length f is then $R/2$.

It is often a good plan to invert the procedure described above and do the reflection part of the experiment first. Then remove the mirror after noting its position and adjust the position of P_2 without disturbing the lens and pin P_1. There is then no danger of wasting time on a position of P_1 which produces an image whose distance from the lens is less than the radius of curvature of the mirror.

Observations: Actual length of index needle =
Observed length of index needle between mirror and P_2 =

S.No.	*Position of convex mirror (cm)*	*Position of image pin P_2*	*Observed R (cm)*	*Corrected R (cm)*

$\therefore$ Index correction =
Mean value of corrected R =
$\therefore f = \frac{1}{2} R =$

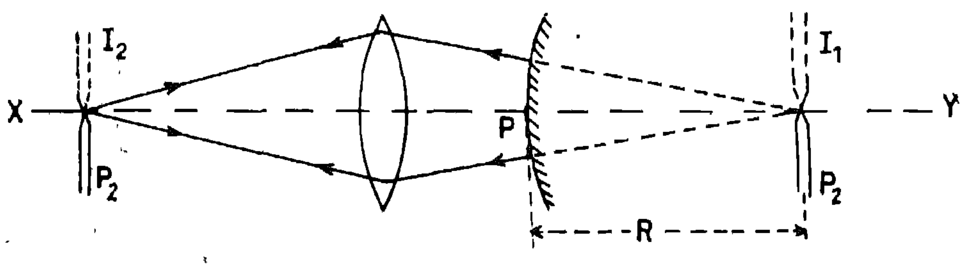

Fig. 5.31

5.23 (Experiment): To find the focal length of concave lens using a convex lens

Apparatus: Concave lens and its upright, convex lens and its upright, optical bench with two mounted pins.

Procedure: Place a mounted pin P_1 at distance from the convex lens greater than its focal length. Locate its real inverted image I_1 on the other side of the lens by removing parallax between the image and second pin P_2 (Fig. 5.32 a). Note the position of pin P_2 on its upright and record it.

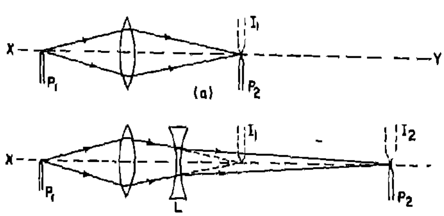

Fig. 5.32

Next, place the concave lens L in its upright between the convex lens and pin P_2 (Fig. 5.32 b). First keep the concave lens fairly near to pin P_2. Observe that the inverted real image has shifted further from the convex lens. Bring the concave lens closer to the convex lens until this shift is fairly large. Now shift pin P_2 and locate the image I_2 by it, by removing parallax between the two. The convex lens or the pin P_1 must not be disturbed during the second part of the experiment. Note and record their positions. Compute u the distance of image I_1 from the concave lens and v the distance of image I_2 from the concave lens. Since the image I_1 acts as virtual object, these distances are related by the lens formula.

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

You may note that, according to the convention of signs, both u and v are positive in this experiment.

Repeat the experiment 3 or 4 times, changing the value of u each time. Find f in each case and find the mean of its values.

Observations: Actual length of index needle = ______________ cm.

Observed length of index needle between L and P_2 = ______________ cm

∴ Index correction = ____________ cm.

S.No.	*Position of I_1 (cm)*	*Position of concave lens, L (cm)*	*Position of I_2 (cm)*	*Observed u* (cm)	Observed v (cm)	Corrected u (cm)	Corrected v (cm)	f (cm)

Mean value of f = ______________ cm.

Notes: 1. The second image I_2 is formed only when the distance between concave lens L and first image I_1 (which acts as virtual object) is less than the focal length of concave lens. If you do not see the real inverted image I_2, you will most probably see it on moving the concave lens nearer to first image I_1. It is a good procedure, therefore, to first roughly locate the image I_2 by using a pencil held in hand, keeping the pin P_2 at image I_1 as a guide to decide which way to shift the concave lens L. After you have seen a clear image I_2 and ensured that it lies within the range of the optical bench, move P_2 to locate its position accurately

2. Since the image I_2 is quite enlarged, it can get blurred by chromatic abration of the two lenses. Thus it is better to put a screen behind object pin P_1 and thus do the entire experiment with one clour of light instead of with white light. For the same reason, pin P_1 should be quite thin and sharp compared to pin P_2

3. Adjust the position of concave lens L so that second image I_2 is sufficiently removed from I_1, to give reliable results.

5.24 (Activity): To study the spherical aberration of a concave mirror

(a) By using the parallax method

Use a large mirror, of at least 7.5 cm diameter and focal length 10 cm. Using a thin and sharp pin P_1 as object, locate its centre of curvature C by removing parallax between the pin and its real inverted image I. Note that on moving your eye laterally, the parallax is perfectly removed (as finely as you can see) whatever portion of the mirror is in the back ground (Fig.5.33). It is so because this point is the centre of curvature for every portion of the spherical mirror.

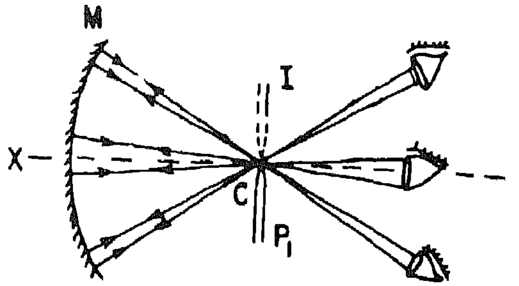

Fig. 5.33

Now move the pin close to the focus F and locate its enlarged real inverted image, by using only the central portion of the mirror. For this purpose, cover the miror by stop A with a central hole of 2.5 cm diameter (Fig.5.34). The pin

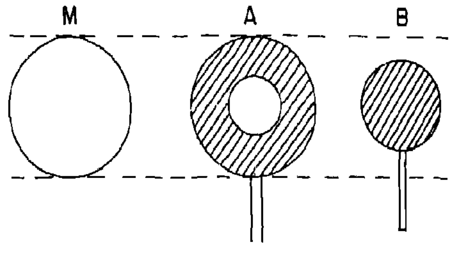

Fig. 5.34

P_2 used for locating the image may be larger than P_1.

Now without disturbing the positions of P_1, P_2 and the mirror, simply change the stop. The second stop, B, is a circle of 5.0 cm diameter. It covers the central portion of the mirror and exposes the ring shaped marginal portion of inner diameter 5.0 cm). Check up the parallax between P_2 and the image produced by this portion of mirror. You find that the pin P_2 has to be moved closer to the mirror to remove the parallex (Fig. 5.35). Hence, focal length of the mirror for marginal rays of light is smaller than that for paraxial rays.

(b) By using a source of light and screen

You can use a tiny torch bulb as object (instead of pin P_1) and a ground glass screen (in place

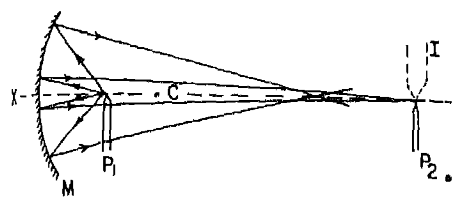

Fig. 5.35

of pin P_2) on which an enlarged image of the filament is projected Since the filament is of substantial length, keep the bulb so oriented that the U-shaped filament lies in a plane perpendicular to axis of the mirror Adjust the position of screen to make a sharp image by paraxial rays. Then replace the stop B to let marginal rays make the image and observe that the screen has to be moved closer. Done in this manner, this experiment is an excellent demonstration to a group of students

5.25 (Activity) : To study spherical aberration of a convex lens.

Use a lens of 60 mm diameter and 10 cm focal length. Find the approximate focal length by focussing the image of a distant object on a sheet of paper.

For object, use a light-box with a small hole (diameter 1 cm) on which a fine wire gauze is fitted. A strong milky electric lamp inside the box illuminates the wire gauze. The torch bulb of experiment 5.24 (b) can also be used for the object. But select a bulb in which the entire U-shaped filament lies in a plane, which may not be so in many bulbs.

Fix the lens L in its upright on the optical bench. Cover it by stop A, a cardboard disc with a central hole of 2.5 cm diameter, so that rays of light may pass only through the central portion of the lens. Set up the illuminated object O, at a distance from the lens just greater than the focal length (Fig 5 36) Place a yellow filter

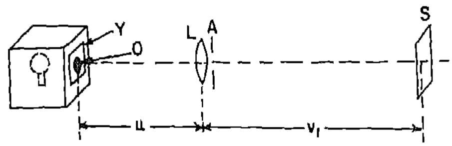

Fig. 5.36

Y in front of the object Obtain the enlarged real image of the wire gauze on the other side of the lens, on a ground glass screen S held in an upright on the optical bench. Make at least three independent adjustments of the position of screen to obtain a sharply focussed image. Note each position of the screen on the screen on the optical bench and find the mean position. Calculate the mean image distance v_1 for paraxial rays.

Without slightest disturbance to the lens and the light box, replace the second stop, B on the lens. It is a disc of diameter 5.0 cm It covers the central portion of the lens and exposes a ring-shaped marginal portion whose inner diameter is equal to the disc (Fig.5 34) Note that the image on the screen gets blurred Again, make at least three independent adjustments of the position of the screen to obtain a sharply focussed image. Note each position of the screen on optical bench thus find the mean image distance, v_2 for marginal rays.

Repeat these observations with the two stops A and B, by increasing the object distance first to double the focal length and then to four times the focal length of the lens. In these cases the image on the screen is quite small and may have

to be observed with a magnifying glass, in order to adjust the position of the screen where the image is the sharpest

From a consideration of the relative values of v_1 and v_2 interpret the results in the light of the following questions

(a) Do the two portion of the lens (central and marginal) have the same focal length? Which portion is of shorter focal length?

(b) How will it affect the image, if the entire lens is allowed to pass the rays of light?

(c) How does the distance of object, u, affect the relative values of f_1 and f_2 the focal lengths for (i) paraxial rays and (ii) marginal rays? (For a double convex lens, in which $R_1 = R_2$, difference between f_1 and f_2 is least when object and image are equidistant from the lens)

5.26 (Activity): To study the chromatic aberration of a convex lens.

Use the same lens and set-up as was used for the study of spherical aberration Use the stop A throughout, which allows the paraxial rays to pass through.

First replace the yellow filter by a red filter Set the object distance, u to double the focal length of the lens. Measure and record the value of v_r. Adjust the screen to receive the red image in sharpest focus. Taking at least three independent readings of the image distance v_r, and obtain the mean value of v_r.

Next, replace blue filter on the object without slightest disturbance to the position of the lens or the object. Adjust the screen to receive the sharpest blue image. Take three independnet readings of the image distance v_b and obtain the mean value of v_b.

From a consideration of the relative values of v_r and v_b, interpret the results in the light of the following questions·

(a) Is the red image in the same position as the blue image? If not, which is nearer to the lens?

(b) How will it affect the image if white light is used, in which red and blue lights are both constituents alongwith many other colours?

Exercise: Since the value of u is known, calculate f_r and f_b, the focal length of the lens for the red light and blue light. Calculate dispersive power, ω, of the glass of the lens.

$$\omega = \frac{f_b - f_r}{f}$$

Where f is the mean of f_r and f_b

5.27 (Activity): To set up a simple astronomical telescope and find its magnifying power.

You can set up a fairly good telescope using simple lenses and see distant objects by it, which are not visible by unaided eye You are familiar with basic construction of an astronomical telescope given in the textbook under chapter 11 (Ray optics and optical instruments). For the objective you can use a good spectacle lens (concavo-convex) or a plano-convex lens of power between +1 D and +2 D (i e. f = 100 cm to 50 cm) and diameter 50 mm. It must be made of a good opthalmic glass and not a cheap one made of window glass. Fix this lens in one upright at one end of an optical bench, convex side away from the centre of optical bench. For the eyepiecs, use a plano-convex lens of any diameter between 20 mm to 50 mm and focal length 10 cm. Fix it in another upright on the optical bench. Convex side of the eye lens should be towards the objective (Fig.5.37).

If your eye piece lens is too small to be fixed in the upright (e.g. when its diameter is 20 mm),

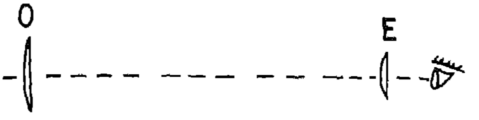

Fig. 5.37

hold it in a hole of same diameter as the lens cut in the centre of a disc C_1, of thick card-board of diameter 50 mm. Two discs C_2 and C_3 of same diameter and having central holes of slightly smaller diameter may be pasted on either sides of C_1 to prevent the lens from slipping out (Fig.5.38)

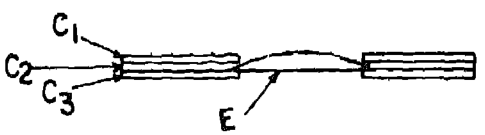

Fig. 5.38

Point this telescope towards a distant object. Adjust the distance between the two lenses, till you see a sharp inverted image of the object with fine details.

To find the magnifying power of your tele-scope, clamp a metre scale vertically at the end of the laboratory or a distant support 10 m to 20 m away. Scale should have 1 cm thick mar-kings 1 cm apart, so that these can be clearly seen by unaided eye at a distance upto 20 m, Focus the telescope till you see a clear inverted image of the scale through the telescope.

Observe the metre scale S directly with one (unaided) eye, say the left eye, LE. Also observe it through the telescope with the other eye, RE (Fig.5.39). Then make adjustment of eye lens

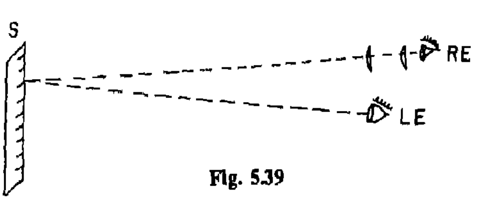

Fig. 5.39

(move towards or away from objective) so that the virtual image seen through telescope is coin-cident with the metre scale itself (i e. at the same distance as the scale seen directly).

The whole telescope may also have to be adjusted laterally and vertically so that image in the telescope is directly alongside the metre scale seen with the unaided eye.

Observe the number of scale divisions as seen through the telescope, which correspond to a certain number of scale divisions seen directly. Their ratio is the magnifying power of the tele-scope.

Note: 1. If the metre scale is not placed distant enough, the magnifying power observed by you may be larger than the theoretical value f_o/f_e Compare your result with the theoretical value and account for the difference

2 If you normally wear spectacles for distant vision, do not remove them for this activity because the metre scale seen directly, as also its image seen through the telescope, are dis-tant from you

3. If, for example, the magnifying power of your telescope is 5 (f_o = 50 cm, f_e = 10 cm), it does not mean that it gives an equal advant-age in resolving the details of objects seen through it. Identify a printed matter in the news-paper which you can read at a distance of about 2 m. Place it vertically and position yourself at the maximum distance from it where you can read it by unaided eyes. Measure this distance, d_e with the help of a colleague using a 3 m carpenters' tape Next, let your colleague carry away this material, holding it upside down, while you look at it through the telescope. Give him a signal to stop when he reaches the max-imum distance at which you can read it through the telescope. Measure this distance d_t from the objective of the telescope. The ratio $\frac{d_t}{d_e}$ gives the advantage in resolving the details that you get by the telescope. Due to aberrations in

the lenses and diffraction, this ratio is often less than the magnifying power

4. Instead of setting up this telescope on the optical bench, you may set it up in two cardboard tubes, TO for the objective lens and TE for the eye lens (Fig.5.40). The objective lens,

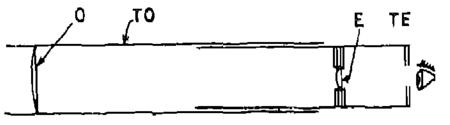

Fig. 5.40

O, of 50 mm diameter is supported about 25 mm inside the end of tube TO facing the distant object The eye lens E, of 20 mm or 25 mm diameter is supported near the end of tube TE, which is near your eye. The eye lens E should also be about 5 cm inside the tube TE so that it makes a real image of the objective lens just outside the open end of tube TE, where your eye is situated. Thus your eye receives all the light passing through the eye lens and thus you see a wide field of view.

The tube TE slides inside tube TO. It should be neither so loose that once focussed at a distant object it may slide in or out at the slightest undesired jerk, nor so tight that in trying to focus it at a distant object when you try to push in or pull out, it often overshoots the correct position. You can use this telescope for watching the night sky. With a magnifying power of about 10 (f_o = 50 cm. f_e= 10 cm), you may be able to see the four Gallilian moons of Jupiter.

5.28 (Activity): To set up a compound microscope and find its magnifying power.

You can set up a fairly good compound microscope using simple lenses and see small objects by it, which are not visible by unaided eye. You are familiar with the basic construction of compound microscope given in the textbook under chapter 11 (Ray Optics and Optical Instruments).

For the objective lens you may use a plano-convex lens of focal length 50 mm and diameter 15 mm By fixing it at the centre of a cardboard disc, as explained in Fig 5.38, in the activity on astronomical telescope Mount it in one upright on the optical bench. For the eye piece use another plano-convex lens of focal length 5 cm and diameter 20 mm. In similar manner mount it in another upright on the optical bench Keep a distance of about 35 cm between the two lenses and their convex surfaces inwards (Fig.5.41) Keep a finger in front

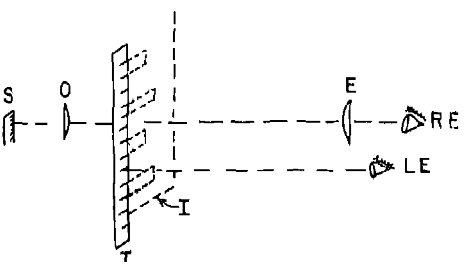

Fig. 5 41

of lens O and look at it through the eye lens E. Adjust the position of your finger till you see it clearly. You see the tiny hair magnified to rope-like appearance. You may also be able to see the tiny holes in your skin, through which you perspire.

To measure its magnifying power keep a small scale S, clamped vertically in a stand, at the same place as your finger. The portion of a 15 cm steel scale which has $\frac{1}{2}$ mm marks, is quite good Set another taller scale T vertically in another clamp stand at the least distance of distinct vision (about 25 cm) from the eye. Keep the scale T close enough to the microscope to enable it to be viewed direct with one eye (say left eye LE), while the scale S is viewed

at the same time through the microscope with the other eye, RE.

Adjust the position of S until its image I seen in the microscope, coincides with the scale T and there is no parallax between them. Observe and record the number of mm divisions on scale T viewed direct corresponding to a small length (say 2 mm) on the scale S viewed through the microscope, and so deduce the magnifying power.

Disturbing the setting of scale S each time and using different lengths on scale S, obtain several readings, find magnifying power in each case and take the mean of all the results.

Note: 1. Since the magnifying power of the compound microscope depends on the distance between objective and eye piece, the result you obtain is for a particular distance between the two For taking the mean of several measurements of magnifying power, this distance should not be altered.

2. You may repeat the experiment by taking a few other distances between the two lenses and thus study the affect of this distance on the magnifying power.

3. It is a considerable help if the two scales (particularly the smaller) are strongly illuminated by electric lamps.

4. It is of considerable help to keep your eye slightly away from the eyepiece E, at a point where the eye piece makes a real image of the objective O. Then you can see the maximum length of scale S through the microscope.

TOPIC 6 : ATOMIC AND NUCLEAR PHYSICS

5.29 (Demonstration): Demonstration of properties of cathode rays using a cathode ray tube with a Maltese cross.

The cathode-ray-tube consists of an electrically heated cathode C, which releases electrons when heated. These are accelerated by a hollow cylinderical anode A (Fig.5.42) which is connected to the positive terminal of an e.h.t. supply

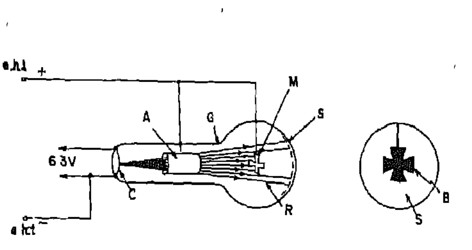

Fig. 5.42

of about 2 kV to 3 kV. The assembly is enclosed in an evacuated glass tube G Thus electrons travel in a divergent beam through the cylinderical anode There is a Maltese cross M in the way of the rays R, which end up at the fluorescent screen S.

When the e h.t is applied to the tube and cathode is heated, you observe a dark shadow of the cross on the screen against a green fluorescent background. Shadow is a true, slightly enlarged copy of the cross You see the same shadow if e.h.t. is not applied and the room is sufficiently dark. The shadow without e h.t. is formed by dim light which is emited by the cathode when it is heated. This suggests that the rays are travelling in straight lines from the cathode and those not intercepted by the cross cause the screen to fluoresce.

Bring a strong magnet near the side of the tube, in level with the cross and near the cross. You then observe that the shadow shifts vertically and has become a bit blurred. If you bring the magnet in level with and near the anode, the beam deflects and the shadow partually or wholly disappears, because the beam misses the cross and passes above or below it. Using Fleming's left hand rule find the kind of charge which must be moving from cathode to the screen You abserve that the rays behave

like a flow of negative charge travelling from cathode to anode.

The negative charge contained in the rays is also evident from the fact that the anode is given a high positive potential, which accelerates the particles released by the cathode In fact you can observe that the higher the potential of the anode, the less the rays bend in a given magnetic field, i e the higher is their velocity. Thus these rays experience force like nagatively charged particles in an electric field

After about 10 minutes of operation, feel the end of the tube where the rays strike the fluorescent screen. You will find that it is a bit warmer than the room. It concludes that these rays carry energy.

The properties of cathode rays thus demonstrated may be summarised as follows:

(i) They travel from cathode in straight lines

(ii) They cause certain substances to fluoresce.

(iii) They possess kinetic energy.

(iv) They can be deflected by magnetic field and they experience force in an electric field, which evidence their negative charge

In another kind of cathode ray tube, the cross has vanes twisted at some angle, like the blades of fan. The cross is also free to rotate. Demonstrate by this tube, that as the rays strike the cross, the cross begins to rotate as if wind is moving it It evidences the following property.

(v) The cathode rays possess momentum.

Thus these are moving particles possessing mass. These are not like light rays or heat rays, which have very little momentum and for a momentum sufficient to rotate the cross, will have to be so intense that they would melt the cross rather than move it.

5.30 (Demonstration): To demonstrate photo-electric effect

You can set up a quite simple experiment to

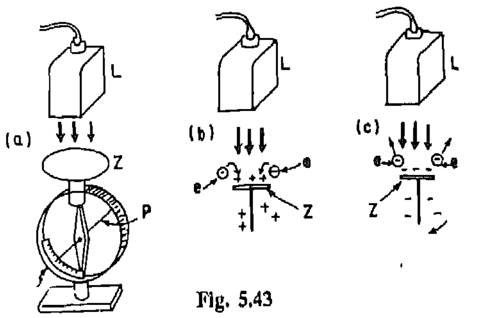

Fig. 5.43

demonstrate that electromagnetic radiation can release electrons from a metal surface Take a small zinc plate and clean its surface with a fine emery cloth Place the zinc plate Z horizontally on the disc of an electroscope E, cleaned face upwards (Fig 5.43a). Charge the electroscope negatively. Let it stand for a minute and see that there is no perceptible movement of the pointer of electroscope in this duration Next, illuminate the zinc plate with ultravoilet light from a mercury vapur lamp L and observe that the electroscope discharges quite rapidly Repeat this experiment with a sheet of glass between the lamp and the zinc plate, which absorbs ultravoilet rays and observe that the electroscope does not discharge As the glass sheet is removed, the electroscope starts discharging. Hence the discharging of electroscope is linked to the ultravoilet rays coming from the lamp.

Repeat the experiment by charging the electroscope positively. This time you observe that ultravoilet rays have no effect on the discharging of electroscope, which goes on at same very slow rate as without the ultravoilet rays and is due to minute leakage within the insulation of the electroscope.

With positively charged zinc plate, as the ultravoilet rays release the electrons from the plate Z, the released electrons are attracted back to the plate at high positive potential (Fig.5.43b) With negatively charged zinc plate, as the ultravoilet rays release the electrons from plate Z, the released electrons are repelled away by the

plate due to its negative potential (Fig 5.43 c). Because only with negatively charged electroscope, the ultravoilet light is observed to discharge the electroscope, this experiment helps to conclude that ultravoilet light releases negative charge (i.e. electrons) from the zinc surface.

Note: The release of electrons by ultravoilet light is most efficient in case of freshly cleaned zinc surface. Thus the experiment should be done within a few minute after the zinc plate is cleaned by emery cloth.

5.31 (Experiment): To study how a radio-active substance decays, using the analogue of a dice.

Apparatus: 100 small cubes of plastic/wood with one face of each marked, a container (e g. a beaker) for shaking and throwing them, a large tray in which to throw the cubes without any one falling on the ground You can easily make a 50 cm x 70 cm tray using a pastal paper of 56 cm x 76 cm, by bending 3 cm at each edge into vertical position.

Background: Earlier in the laboratory Manual Vol.I (for class XI), under the activities 2.26 and 2.27 on pages 45 to 48 titled "How does a container empty out through a leak" and "Measuring time interval by the water clock" the idea of "half life" for the fall of water level in the jar was introduced. These activities were based on the fact that variation of amount of water in the container with time is represented by the same mathematical formula, as represents the decay of an actual radio-active substance.

In the present experiment we shall represent individual radio-active atom by a small cube and go a step deeper to understand the role of chance phenomenon in radio-active decay.

Procedure: Take one hundred cubes in the container and throw them on the tray. Make sure that you throw in such a way that all the cubes spread out and there is no piling up of cubes at any spot. All the cubes with marked face up are to be considered as decayed. These are taken out, counted and the number left in the tray are again taken in the container and the whole process is repeated. After 15 throws (which repesent 15 units of time elapsed) only a few 'undecayed' cubes are left. Enter the observations of these 15 throws under set 1 in the table of observations, indicating the number of 'decayed' cubes under column (a) and of the 'undecayed' cubes under column (b)

Repeat the entire experiment (set of throw) four times more, each time starting with 100 dice and making 15 throws Enter the results of these 4 experiments in the remaining four sets of columns.

Plot points representing N, the number of 'undecayed' cubes, against serial number of throw, t, for each of the five experiments on the same graph, taking t along X-axis and N along Y-axis. Obviously all the five experiments are identical, though the value of N for same value of t may be different in each experiment. These differences are due to the fact that 'decay' of a dice in these experiments is a chance phenomenon. Draw a smooth curve which best represents this experimet. Value of N for any particular value of t by this graph may or may not be an integer. Actual points representing the observations in the five experiments are widely away from the graph above and below it. Find from the graph the 'half-life' for decay (i.e. the number of throws necessary for half the original number of dice to stay undecayed). Find the half-life in- various parts of graph ($N = 100$ to 50, or 60 to 30, or 40 to 20, or 30 to 15). If these results are equal within experimental error, find the mean half life.

Notes: 1. You can see that for any particular value of t (number of throws) the number of undecayed atoms (cubes) is not exactly same in the five experiments. It so happens because decaying of cube is a chance phenomenon. Pro-

Observations: No. of cubes (a) decayed, (b) undecayed.

SNo of throw (t)	Set 1		Set 2		Set 3		Set 4		Set 5		The 500 dice set
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	
0											
1											
2											
—											
—											
15											

bability of decaying of a cube in unit time is 1/6 in these experiments. In like manner in an actual radio-active substance too, the decay of an atom is a chance phenomenon Probability of an atom to decay in unit time (1s) may be a small as 0.5 x 10^{-11} (for carbon -14) and it may be as large as 10^{-1} (for carbon -10). Range is much wider for all the known atoms

2. Equality of half-life in various parts of the graph demonstrates a property of any phenomenon which depends on chance, as the decay of cubes in these experiments as well as radioactive decay is Number of atom (or cubes) that are expected to decay in unit time is proportional to the number of undecayed atoms (or cubes) present

3 For each serial no. of throw, total up all the 5 values of number of undecayed cubes These totals represent an experiment of 500 cubes in which you throw 100 cubes at a time, only for convenience of counting the number of decayed cubes. Plot a second graph on a separate graph paper for these numbers. Observe that deviations of various points from the smooth curve are now smaller. Thus, you can see that when in a radio active sample there are billions of billions undecayed atoms present, the law of decay is quite accurate

TOPIC 7 STUDY OF THE UNIVERSE

5.32 (Experiment): To measure the angular diameter of sun

Apparatus: A plane mirror and a graph paper screen, both mounted on clamp stands.

Procedure: Fix a small plane mirror, M, outside in sun-shine in a clamp stand. Cover it with a paper, in the centre of which there is a small circular hole of diameter a (about 15 to 20 mm) Measure the diameter of this hole Orient the mirror such that it sends a beam of sunlight horizontally into the room If you receive this beam

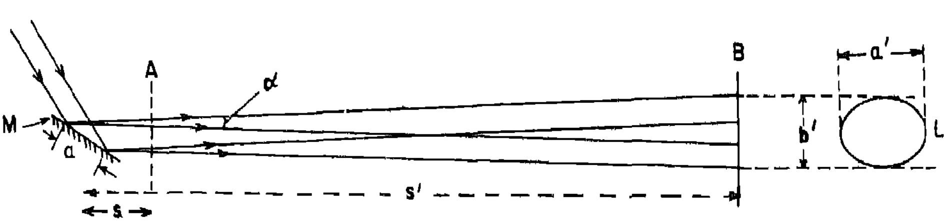

Fig. 5.44

Observations

S.No	Distance from mirror, s (cm)	Dimensions of light patch		Angular diameter of sun		
		Major, a (cm)	Minor, b (cm)	by major dimension	by minor dimension	Mean

on a screen placed perpendicular to the beam and close to the mirror (at position A in Fig.5.44), then you receive an elliptical patch of light of major axis equal to diameter of the hole, a. Hold the screen (a graph paper) with one set of lines on it parallel to this major axis. Measure both the axes a and b of this ellipse and distance s of screen from mirror.

When you move the screen away from the mirror along the beam of light, the patch of light expands, because from each point on the mirror you are receiving a cone of light of vertical angle equal to angular diameter of the sun. Keep the screen at position B. At a distance s' (about 5 m) from the mirror without changing the orientation of lines on it. Measure the major and minor dimension a' and b' of this light patch L, along the two sets of lines on the screen Also measure the distance, s' of the screen from the mirror. Then angular diameter of the sun is

$$\alpha = \frac{a' - a}{s' - s} = \frac{b' - b}{s' - s}$$

Calculate the two results and find the mean value. The unit for this result is radian.

Note: 1. If the room into which you reflect the beam of sunlight is fairly dark, you can make the hole in the paper so small that its dimension can be neglected and it can be treated as a point. Then the patch of light on the screen at a distance s is circular and a clear image of sun. Measure its diameter and divide by s.

Exercise: Assuming distance of the sun as 150 million km, calculate the diameter *(d)* and radius (r) of sun in km.

Food for thought. You know angular diameter of sun changes during the year, as the distance of the sun changes. You have made the astronomical telescope, vide note 4 in activity 5.27 and shown in Fig 5.40. How can you modify the above experiment using that telescope to project an image of sun and measure angular diameter of the sun so accurately that you can study the variation of it during the course of an year?

5.33 (Activity): Identify constellations and stars with the help of star map published in newspaper

You must have seen the star map which appears in newspapers every month. It shows the sky in two halves. One half is the part you see when you stand facing south and the other half is the part you see when you stand facing north. Both parts are joined in the middle, which represents zenith, the sky directly above you. The position of stars changes with time. It is also not same everyday at same time by the clock. Thus the positions shown in the map refer to times and dates indicated. For everyday after the indicated date go back by four minutes in time and your map will faithfully show the star positions.

There are other useful star maps too which

are easy to set for any date and time for example the star map kit at S.No. (ii) in the list at the end of this theme. You can also use more detailed star atlases, as the ones at S.No. (iv) and (v), if you spend some time in reading and following the instructions given and if you get familiar with coordinates in the sky

5.34 (Activity): Estimating angular distance between two objects in the sky

While you study the objects in the sky with the help of a star chart, you frequently need to estimate angular distance, i e. angular separation of two objects as seen by you. The simplest devices to estimate angular distances in the sky are your own (i) palm (ii) fist, (iii) thumb, and (iv) fore-finger. Not ony for objects in the sky, for distant terrestrial objects too, you can use these devices. Stretch your one hand in front of you horizontally, and also stretch its palm. Then the palm length (distance between tips of the little finger and thumb) subtends an angle between 16° and 20° at your eyes. You can calibrate your palm length more precisely as follows:

Stand in an open place Start from horizon in your front, with a hand and the palm stretched in front of you. Count the palm-lengths from horizon in front to zenith and then to horizon at the back. Then the total angular distance from horizon to horizon being 180°, the angular size, α, of your palm length is

$$\alpha = \frac{180°}{\text{number of palm-lengths from horizon to horizon.}}$$

In this procedure, the number in the denominator need not be necessarily an integer. If in the last position of your palm, the direction of horizon at the back is, for example, in the middle of the palm, count it as half.

Since the fist is about half the palm-length, angular width B of the fist is half of α. Better is that you calibrate the fist itself by the above method.

Now, thumb-width is about $\frac{1}{10}$ to $\frac{1}{8}$ of the palm-length and fore-finger width is about $\frac{1}{15}$ to $\frac{1}{10}$ of the palm-length. In order to find more precisely these fractions for *your* thumb and *your* fore-finger, mark out a distance equal to the palm-length on a sheet of paper Then count the number of thumb-widths and fore-finger-widths in it. Thus find the angular size of thumb-width (γ) and fore-finger-width (δ).

Having calibrated the four devices, you can proceed to estimate the angular distance between two stars in the sky Start from any one of the stars, count the number of, say, palm widths and thumb-widths upto the second star. Use any combination of the four devices, add up their angular width and the result is the angular distance between the two stars

You may use these devices to estimate the latitude of your place. Locate the pole star in the sky. Estimate the angular distance between pole star and horizon in the north direction, as described above. The result is the latitude of your place. With some preacice, the error in your result should not exceed 2° or 3°.

5.35 (Activity): Observation of objects in the sky through a good telescope.

If your school has, or can acquire a good amateur telescope, organise sessions to observe celestial objects in evenings through it. Such a session is best organised on the evening before a holiday, so that you can afford to reach home late in the night after this session. Quite good telescopes with objective mirrors of upto 13 cm diameter (reflecting type) and with achromatic objective lens of upto 8 cm diameter are available in India at moderate cost. If you possess the common binoculars with objective lenses of 50mm diameter, this too can be used and objects in the sky that you can see with it will

create a lot of interest.

A few example of interesting observations in the sky are·

(a) *Surface of moon*: mountains and many other features on it

(b) *Planets* and objects orbiting them, e.g. rings of Saturn, moons of Jupitar (I, Europa, Ganymede and Callisto, first seen by Gallileo without an achromatic objective lens in the telescope invented by him).

(c) *The Milky Way*. i.e. our own galaxy which, by unaided eye, appears like a band of cloud in a great circle around the sky (and hence named as Akash Ganga by Indian astronomers). By a telescope you see large number of bright stars. The more powerful is your telescope, the more beautiful the Milky Way you see.

(d) *Stars of various colours*: You can make out different colours of brighter stars by unaided eye too, with some practice. Due to their different temperatures stars have different colours ranging from red to blue.

(e) *Star Clusters*: like Pleiades and Beehive cluster, which are groups of stars very close together. A star cluster may also have a fuzy spot where stars are so close together that your telescope can not see them separate.

(f) *Galaxies* like the Andromeda, which appears as a fuzzy spot in sharp contrast to stars, which are points of light.

(g) *Variable stars*: Some stars like δ-Cephei continuously change in their brightness.

(h) *Sunspots*: Project an image of sun in day time and see many sun spots and study the rotation of sun.

In order to organise such viewing systematically and to have concrete learning out of these, rather than casually viewing the Magic show of God, the best is to organise an astronomy club, if you can get a room at a roof top or any other place from where the sky can be seen unhindered, and where your equipment can be kept safe, and can be taken out for the sky viewing by spending little time and effort. During day time, this room can be used for science related co-curricular activities. If you find it difficult to organise an astronomy club in your school, you can visit a school or college nearby, where you can reach in an hour or so by your school/public transport, and where an astronomy club is functioning

If the astronomical telescope in your school has (i) the objective mirror of about 18 cm or bigger or objective lens of about 13 cm or bigger, and (ii) has facility of equatorial alignment (i.e. making one of the two axes of rotation of the telescope parallel to axis of rotation of earth), then to derive full benefits that your telescope is capable of, you should instal it in an "observatory" of your school permanently (at least for a viewing season). Roof of the observatory may be sliding, which can be wheeled off when you want to make observations. Better still, your observatory can be a rotating hut, with a slit in the walls and roof through which the telescope can see the sky. It is quite easily possible to make a rotating hut of 4 m diameter at moderate cost, which can be rotated by two persons at opposite ends of any diameter of the hut.

For this activity you will find the following publications quite useful. There are, of course, many other too.

(i) Shankar, P.N. 1985 *A Guide to the Night Sky*. Karnataka Rajya Vig-

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nana Parishat, Bangalore 560 012.

(ii) *The Star Map Kit*, Nehru Planetorium, Teen Murti Bhavan, New Delhi -110 011

(iii) Shankar P.N. 1985, *Clusters Nebulae and Galaxies*, Karnataka Rajya Vignana Parishat, Banglore 560 012

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DATA SECTION

TABLE 1

Dielectric Constants of Common Materials

Material	*Temperature* (°C)	*Frequency* (Hz)	*Dielectric constant*	*Loss tangent* (10^{-4})
Amber	20	10^6	2.8	2
Amber	20	3×10^9	2.6	90
Soda glass	20	10^6	7.5	100
Fused quartz	20	10^3 to 10^8	3.8	2
Liquid Paraffin (Medical Grade)	20	10^3	2.2	1
Transformer oil (Class B)	20	10^3	2.2	1
Marble	20	10^6	8	400
Sand (dry)	20	10^6	3	-
Sandstone	20	10^6	10	-
Paper (Oil impragnated condenser tissue)	20	10^3	2.3	22
Mica	20	10^3 to 10^8	5.4 to 7	2
Epoxy resin (e.g. Araldite)	20	10^6	3.3	250
Cellulose Acetate	20	10^6	3.5	300
Vinyl Acetate (Plasticised)	20	10^6	4	500
Vinyl Chloride (P.V.C.)	20	10^6	4	600
Ebonite (Pure)	20	10^6	3	90
Rubber (Vulcanized soft)	20	10^6	3.2	280
Rubber, Synthetic	20	10^6	2.5	40
Paraffin wax	20	10^6	2.2	2
Sulphur	20	3×10^9	3.4	7
Walnut wood (dry)	20	10^7	2.0	350
" (17% moisture)	20	10^7	5	1400
Vacuum	NA	any	1.00000	Nil
Air	20	Upto 3×10^9	1.00054	negligible
Porcelain	20	10^6	5.5	80
Barium titanate	20	10^6	1200	160
Rutile group	20	10^6 to 10^9	40 to 80	3 to 30
Water	20	10^9	80	650
Water	20	10^{10}	64	4700

TABLE 2

Typical Objects with Electrostatic charge

	Object	*C*	*V*	*Q*	*Energy* $E=\frac{1}{2}CV^2$
1	Ballon of 20cm diameter rubbed all round by nylon cloth	11 pF	200 V	2 2 nC	0 22 μJ*
2.	Metal sphere on insulated stand rubbed by silk (dia 9 cm)	5 pF	500 V	2 5 nC	0 62 μJ*
3	-do- changed by a school type Van-de-Graaff	5 pF	0 25 MV	1 25 μC	0 16 J
4	Boy on an insulated stool repeatedly charged by electrophorus	50 pF	3000 V	150 nC	225 μJ *
5.	30 cm x 30 cm improvised condenser with wax soaked tissue paper dielectric (K = 2 7, A= 700 cm and d=0 4mm) and charged by a 9V battery.	4 nF	9V	36nC	162 nJ *
6	-do- plates separated to 2 cm apart	80 pF	450 V	36 nC	8 1 μJ *
7	Flash gun condensers (Professional type)	500 μF	400 V	0 2 C	40 J
8	Average lighting between earth and cloud (h=1 to 5 km)		10^8 V to 10^9V	20 C	10^9 to 10^{10}J
9	(a) Earth and ionized air of high conductivity at top of stratosphere (h = 50 km)		0,4 MV	5 7x10^5C	10^{11}J
	(b) Ionization current between earth and ionosphere in fair weather	--	0 4 MV	1800 C/s	7x10^8J/s
10	Charged plate of good electrophorous (diameter 20 to 30 cm) in dry weather, after lifting it up	10 pF	3000 V	30 nC	45 μJ *

* These bodies in your school laboratory are not dangerous to touch

TABLE 3

Electrical Resistivities of Typical Metals and Alloys

Material	*Resistivity* (10^{-8} ohm-metre)				*Temperature coefficient at* 0°C *(over range* 0°C-100°C) (10^{-4})
	0 °C	*100 °C*	*300 °C*	*700 °C*	
Aluminium	2 45	3.55	5.9	24 7	45
Chromium	12.7	16 1	25 2	47 2	
Copper	1 56	2 24	3 6	6 7	43
Iron	8 9	14.7	31 5	85 5	65
Lead	19.0	27 0	50	107 6	42
Gold	2 04	2 84			40
Mercury	94.0766*	103 5	128		10
Nickel	6 14	10.33	22 5		68
Platinum	9 81	13 65	21 0	34 3	39 2
Platinum-Rhodium (87/13)	19 0	22 0			15 6
Platinum Rhodium (90/10)	18 7	21 8			16 6
Platinum Iridium (90/10)	24 8	28 0			13
Silver	1 51	2 13	3 42	6 5	41
Tin	11.5(20°C)	15.8	50	60	46
Tungsten	4 9	7 3	12 4	24	48
Zinc	5 5	7.8	13 0	37(500°C)	42

Mercury at 0°C is used as a secondary standard to realize the standard unit of resistance, ohm

TABLE 4

Electrical Resistivities of Common Insulators and Semiconductors

Substance	*Resistivity* (ohm-metre)	*Substance*	*(Resistivity* (ohm-metre)
Diamond	10^{10} to 10^{11}	Carbon 0°C	$3\ 5 \times 10^{-5}$
Ebonite	10^{14}	" 500°C	$2\ 7 \times 10^{-5}$
Glass (Soda lime)	5×10^{9}	" 1000° C	$2\ 1 \times 10^{-5}$
" (Pyrex)	10^{12}	" 2000° C	1.1×10^{-5}
" (conducting)	5×10^{6}	" 2500° C	$0\ 9 \times 10^{5}$
Mica	10^{11} to 10^{15}	Germanium 0°C	0.46
Paper (dry)	10^{10}	Silicon 0° C	2300
Paraffin wax	10^{14}		
Porcelain	10^{10} to 10^{13}		
Sulphur (rhombic)	2×10^{21}		

TABLE 5

Alloys of High Resistance

Alloy	*Resistivity 20°C* (10^{-8} ohm-metre)	*Temperature coefficient in range 0-100°C* (10^{4})	*Max Operating temperature (°C)*
Constant (58 8% Cu 40% Ni, 1 2% Mn)	44 to 52	-0.4 to +0 1	500
German Silver (65% Cu, 20% Zn, 15% Ni)	28 to 35	+0.4	150 to 200
Manganin (85% Cu, 12% Mn, 3% Ni)	42 to 48	0 3	100
Nickeline (54% Cu, 20% Zn, 26% Ni)	39 to 45	0 2	150-200
Nichrome (67.5% Ni, 15% Cr, 16% Fe, 1 5% Mn)	100 to 110	2 0	1000

TABLE 6

Transition Temperature to the Superconducting State

Substance	*Transition temperature* (K)	*Substance*	*Transition Temperature* (K)
Metals		*Compounds*	
Candmium	0.6	NiBi	4 2
Zinc	0 8	PbSe	5 0
Aluminium	1 2	NbB	6.0
Uranium	1 3	Nb_2C	9 2
Tin	3 7	nBC	10 1 to 10.5
Mercury	4 7	nBN	15 to 16
Lead	7 3	Nb_3Sn	18
Niobium	9 2	$YBa_2Cu_3O_7$	90

TABLE 7

Resistivities of Electrolytes in Aqueous Solution at 18°C

Solute	*Concentration* %	*Resistivity* ρ, (ohm cm)	*Temperature coefficient*, χ (degree^{-1})
Ammonium Chloride NH_4Cl	5	10.5	0.0198
	10	5.6	0.0186
	20	3.8	0.0161
Copper Sulphate $CuSO_4$	5	52.9	0.0216
	10	31.5	0.0218
	17.5	23.8	0.0236
Sodium Chloride NaCl	5	14.9	0.0217
	10	8.3	0.0214
	20	5.1	0.0716
Sulphuric acid H_2SO_4	5	4.8	0.0121
	20	1.5	0.0145
	30	1.4	0.0162
	40	1.5	0.0178
Zinc Sulphate $ZnSO_4$	5	52.4	0.0225
	10	31.2	0.0223
	20	21.3	0.0243

Note The resistivity of an electrolyte falls off with increasing temperature (as distinct from metals). The resistivity ρ_t for any temperature t can be computed from the formula

$$\rho_t = \rho_{18}\,(1 - \chi\,(t-18))$$

where χ is the temperature coefficient given in the table, and ρ_{18} is the resistivity at 18°C

TABLE 8

Thermo-e.m f. generated by various Thermocouples

Thermo couple	*Thermo e m f for cold junction at 0 ℃ and hot one at 100 ℃ (μV)*
Copper-constant	4160
Copper-iron	1220
Copper-nickel	2240
Iron constantan	5380
Iron-nickel	3460
Iron-aluminium	1560
Aluminimum constantan	3820
Aluminium-nickel	1900
Constantan-nickel	1920
Copper aluminium	340

TABLE 9

Atomic Weights, Valency and Equivalent Weights of Common Elements

S.No	*Element*	*Symbol*	*Atomic Weight*	*Salt*	*Valency*	*Equivalent Weight*
1	Bromine	Br	79 904	NaBr	1	79.904
2	Calcium	Ca	40 08	$CaCl_2$	2	20 04
3	Chlorine	Cl	35 453	NaCl	1	35 453
4	Chromium	Cr	51 996	Cr_2O_3	3	17.332
5.	Copper	Cu	63 546	$CuSO_4$	2	31.773
6.	Gold	Au	196.967	$AuCl_3$	3	65.656
7	Hydrogen	H	1 00797	H_2O	1	1.00797
8	Iron	Fe	55 847	$FeCl_2$ $FeCl_3$	2 3	27.924 18 616
9.	Nickel	Ni	58 71	$NiSO_4$	2	29 36
10	Oxygen	O	15.9994	H_2O	2	7.9997
11	Silver	Ag	107.868	$AgNO_3$	1	107.868
12	Sodium	Na	22.9898	NaCl	1	22.9898
13.	Tin	Sn	118 69	$SnSO_4$	2	59.34
14	Zinc	Zn	65.37	$ZnSO_4$	2	32.68

TABLE 10

Properties of some high permeability Alloys

These alloys have a high permeability, which decreases sharply at high field intensities (when magnetisation approaches saturation value) and in addition, depends strongly on mechanical strain Initial permeability, and maximum permeability respectively mean the slope of B-H curve for $H=0$ and maximum slope of B-H curve. The coercive force is the value of magnetic field intensity needed to reduce the residual magnetic induction (called retentivity) to zero (its direction is opposite to that of retentivity)

Alloy	*Initial Permeability* (gauss/oersted)	*Maximum Permeability* (gauss/oersted)	*Saturation value of magnetisation* (gauss)	*Coercive force* (oersted)
Giperom 50	3,400	28,000	--	0 06
Giperom 766	14,000	45,000	--	0 04
Pure iron	200	5,000	21,500	1.0
Molybdenum-permalloy (1% Mo)	2,000	120,000	8,500	0 02
Chromium permalloy	3,000	150,000	6,500	0 015
Super permalloy (5% Mo)	100,000	800,000	7,500	0 004

TABLE 11

Properties of some Materials for Making Permanent Magnets

Material	*Coercive force* (oersted)	*Retentivity* (gauss)
Alnico	500	7,000
Alnisi	800	4,000
Magnico	550	12,000
Cobalt steel	220	9,000
Platinum alloys	1500 to 2700	4500 to 5800

APPENDIX 1

Make your own wax-soaked tissue paper for making a capacitor

Take a sheet of thin paper (the one used for making kite or for typing many carbon copies) of size 33cm x 38cm Its thickness is about 0.2mm. Fold a 2cm x 33cm strip of metal in one edge of 33cm length and hold it by a clip This functions as a hanger by which the paper can hang plane without wrinkles

Take an aluminium sheet of 40cm x 40cm and thickness 18 SWG Bend about 2 5cm of each edge angle of about 45° Thus you get a 35cm tray of depth about 1 5cm (Fig A-1) Melt about 0 5 kg

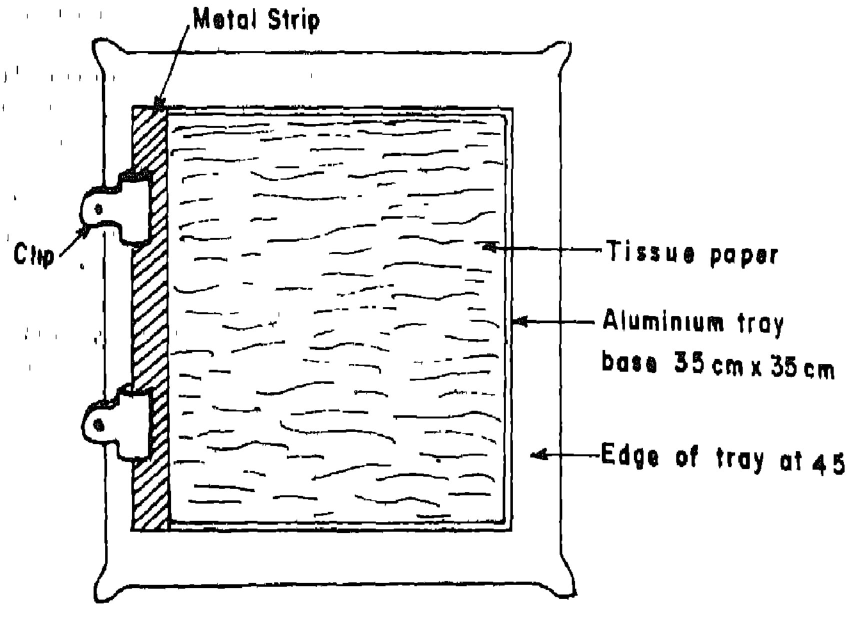


Fig A-1 Improvised tray for melting wax for making wax-soaked tissue paper

of white paraffin wax in it on a smokeless fire or electric stove The wax melts into a clear liquid filled to an average depth of 5mm in the tray The liquid should be hot enough so that its viscosity appears to be similar to that of water but must not be so hot as to create a fire hazard

Hold that paper by the clip and lay it flat on the liquid wax There must be no air bubble between the two. Now slowly lift the paper by the paper clip at a speed of about 1 cm per second so that excess wax has sufficient time to flow back to the tray When the entire paper has been lifted, let it cool for a few minutes Trim the paper on all the four edges because wax layer may be too thick at the edges Thus make a wax-soaked paper of 30cm x 30cm.

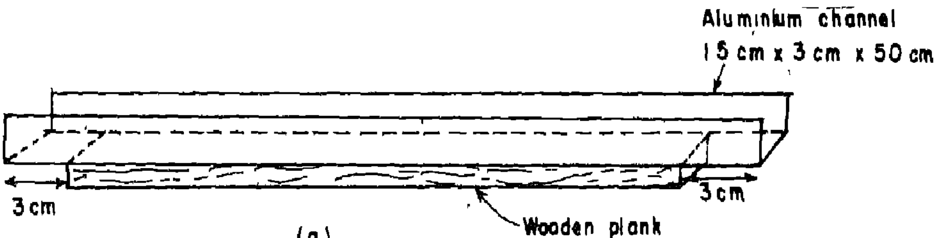
Put this wax soaked-paper as dielectric in your improvised capacitor (activity 1.33) with an average separation between the plates less than 0 4mm, it makes a condenser of capacity more than 4000 pF. If the paper is not punctured any where and wax covers its entire area, you can safely charge it up to 500 volt by a high tension d c power supply

APPENDIX 2

Guideline for Making a Mechanical Model of 'Electron Drift' in a Metal Wire

Take a straight aluminium channel AB, about 3 cm wide and 50 cm long (Fig. A-2a) The atoms/ions(+ve) are to be represented by fixing the smallest size of bicycle steel balls (about 3mm diameter) and the free electrons by the small beads (used in the electrostat machines) free to move when the channel is given a slant The steel balls are to be fixed after putting, carefully, equal quantity of a strong adhesive (say araldite) on each ball just enough to stick the lower tip of the ball to the aluminium surface and not to provide resistance to the drifting tiny beads when these would collide the steel balls Before doing this points have to be marked all along the channel by repeating the pattern of a crystal lattice network (Fig A-2b). This pattern can be achieved more accurately by sticking a strip of graph paper equal in size to that of the channel Mutual gap among balls should be about twice the size of the beads representing electrons

To make the base of the channel stable, it is good to fix it over a wooden plank of the same width but 6 cm smaller length, having a thickness of about 2.5 cm by using a strong adhesive (and not by fixing screws)



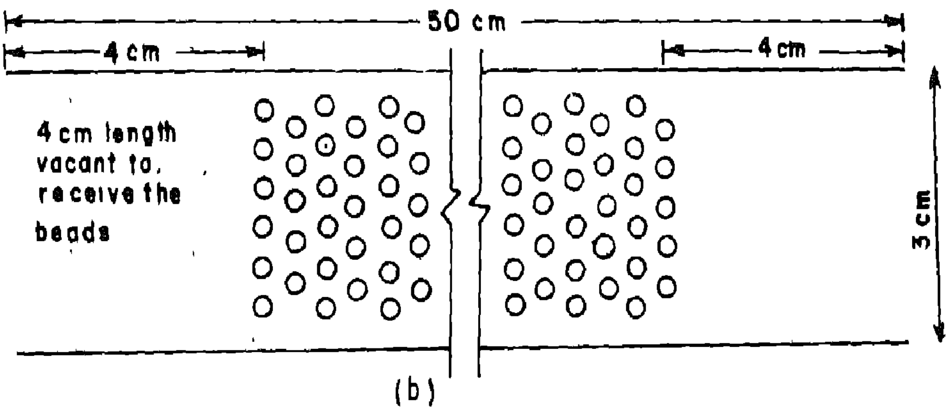


Fig A-2 Making mechanical model of "electron drift"
(a) Fixing up aluminium channel on a wooden plank
(b) Fixing ball bearings on the channel in the pattern of face-centred crystal lattice
NOTE: This figure is not to scale

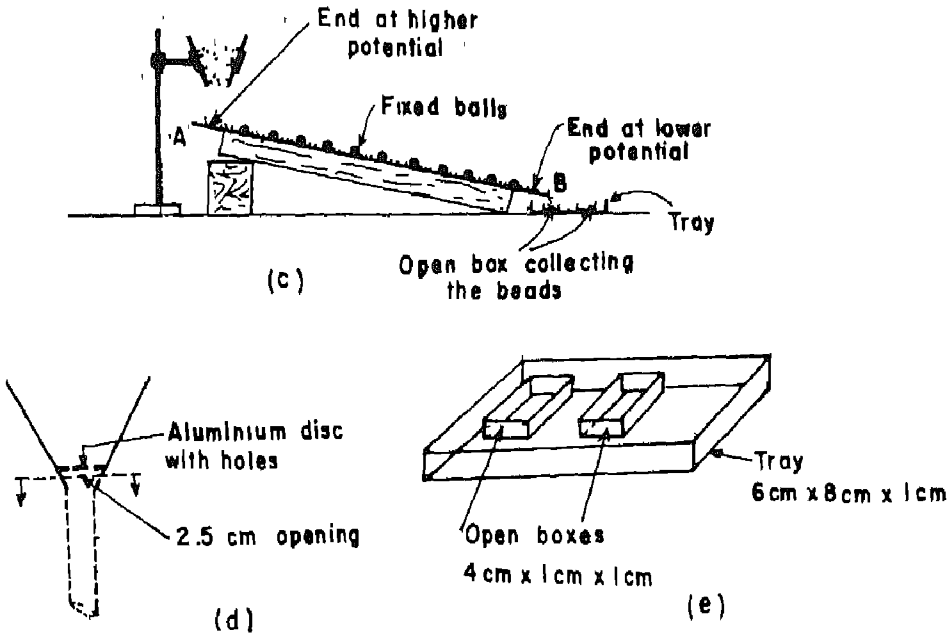


Fig A 2(c, d, e)

(c) Complete set up of the demonstration
(d) Making the device which constantly feeds the small beads at upper end of the channel
(e) Open and dry boxes for collecting the beads at lower end of the channel

For the tiny beads to keep adding at upper end of the channel and colliding with balls and drifting along the channel a suitably modified plastic funnel filled with beads may be kept close to this end, after supporting it in a ring stand (Fig.A-2c). The modification to be done to the funnel is by way of cutting it carefully so that its lower side has an opening of about 2 5 cm diameter Inside this lower end is placed a circular aluminium sheet with about ten holes in it, which are of size just sufficient to allow one bead each to fall from a hole (Fig A-2d). You would also need a few blocks/wedges, 2 to 3 cm thick, to provide a desired slope to the channel for the tiny balls to keep drifting and colliding with the balls a tray with a pair of small open boxes would be needed for collecting the beads at the other end of the channel (Fig A-2 e) The box filled, say upto 3/4th, with the beads would help in transferring 3 cubic cm of the beads at a time to the end at higher potential, after the other box is kept to collect the beads reaching the end at lower potential.

Resistors and Codes to Indicate their Values

Carbon resistors are made from mixtures of carbon black (a conductor) clay and resin binder (non-conductor). The mixture is pressed and moulded into rods by heating The resistivity of the mixture depends on the proportion of carbon The stability of such resistors is poor and their values are usually only accurate to within ± 10% but they are cheap, small and good enough for many jobs (Resistors of accuracy ± 5% are also available). Three sizes are available with power ratings of 1/2, 1 and 2 watts. The value of a resistor is usually shown by colour markings, as shown in Fig A-3a Figures associated with different colours are as under.-

Figure	*Colour*	*Figure*	*Colour*
0	Black	5	Green
1	Brown	6	Blue
2	Red	7	Violet
3	Orange	8	Grey
4	Yellow	9	White

The tolerance colours are gold ± 5% silver ± 10%, no colour ± 20%

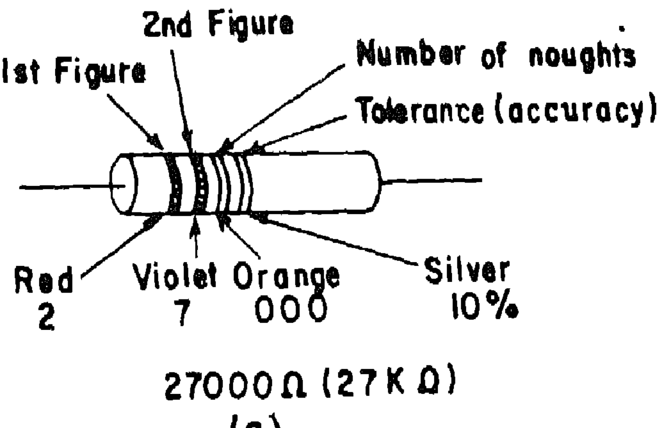


Fig A-3(a) A carbon resistor with colour code marking

This colour code is now being replaced by code with simpler marking, which may be understood by following examples

Value	0.27Ω	1Ω	3 3Ω	10Ω	220Ω	1000Ω
Mark	R27	1RO	3R3	10R	K22	1KO
Value	1200Ω	68KΩ	100KΩ	1MΩ	6.8MΩ	470KΩ
Mark	1K2	68K	M10	1M0	6M8	M47

In this system the tolerances are indicated by adding a letter·
F = ± 1%, G = ± 2%, J = ± 5%, K = ± 10%, M = ± 20%
Examples 5K6K = 5 6 KΩ ± 10%
M47J = 470K Ω ± 5%
K10F = 100 Ω ± 1%

Carbon film resistors have recently gained popularity The stability and accuracy of this type of resistor is commonly ± 2% and the power rating 1/8 to 1/2 watt. Its construction is as shown in Fig. A.3b

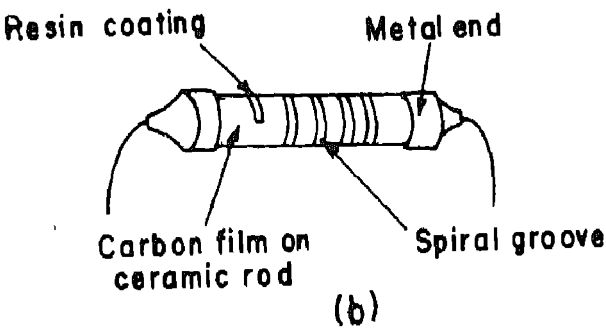


Fig A-3(b) A carbon-film resistor

A ceramic rod is heated to about 1000°C in methane vapour which decomposes and deposits a uniform film of carbon on the rod The resistance of the film depends on its thickness. Resistance of the film can further be manipulated by increasing it by cutting a spiral groove in it The thinner and longer is the resulting spiral of carbon film connecting the two metal ends, the larger is its resistance After cutting spiral groove, the film is protected by a layer of epoxy resin coating

For high accuracy and stability, resistors are always made of wires, as are those required to have a large power rating (i e over 2 watts) They use the fact that the thinner and longer is the wire, the larger its resistance Manganin (manganese, copper, nickel alloy) wire is used for high precision standard resistors because of its low temperature coefficient of resistance (=10^{5}per °C) Constantan (or eureka), an alloy of copper and nickel is used for several purposes (temperature co-efficient ± 2 x 10^{5} per °C, unpredictable). Nichrome (nickel, chromium alloy) wire is used for commercial resistors and heating elements (temperature coefficient 10x10^{5} per °C)

APPENDIX 4

An Improvised Open-type Fuse Holder

To demonstrate the functioning of a fuse, this type of fuse holder is quite useful in the class room The fuse wire is quite visible to students against a white back ground The burnt out fuse wire can be replaced in just about 5 to 10 seconds.

Take two equal wooden strips each about 5 cm long, 6 mm thick (1/4"), 25 mm broad Grind one end slightly taper in each strip on a sand paper Stick the tapered ends together with a strong adhesive to make an inverted V-shape (Fig A-4). On two crocodile clips solder about 1 meter each of flexible electric cable as lead It should be of 15A capacity, made of tinned copper wires Stick the two crocodile

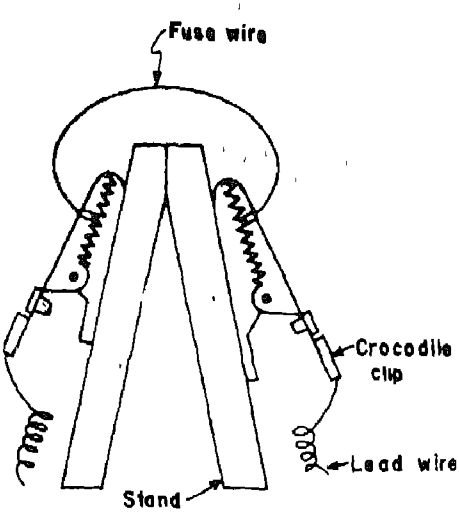


Fig A-4 An open type fuse holder

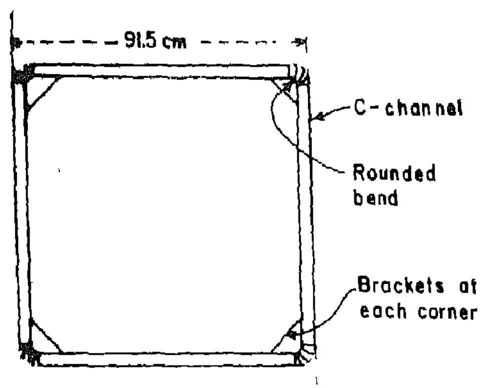


Fig A-5 Large square coil for study of magnetic field produced by a straight conductor

clips on the two sloping arms by a strong adhesive (like araldite) The fuse holder is now ready.

To attach a fuse wire in it take about 12 cm length of fuse wire On the outer jaw of a crocodile clip, wind two turns of one end of the wire Similarly, attach other end to the other crocodile clip, leaving a loop of about 5 cm to 6 cm of wire in the middle

APPENDIX 5

Making a square coil for study of magnetic field produced by a straight conductor, using only two dry cells as current source

Take an aluminium C-channel available in 4 yard or 366 cm length Make a square of it with each side being 1/4th of the total length i e. 91 5 cm (Fig A 5) Width of channel should be 6 mm or [illegible] is available Each corner of the square is round To further strengthen the corners, a [illegible] nate shape is fixed at each corner

In this square wind 40 turns of 24 SWG enamelled copper wire Resistance of this coil at 20°C is about 11 ohm Hence even by a battery of 2 dry cells in the common battery box, which gives an e m f of 3 V, you may pass a current of upto 250 mA in the coil This makes total current in all the conductors of one arm taken together equal to 10 amperes, which gives a neutral point at a distance of about 6 cm in the presence of earth's magnetic field. A 12 volt d c power supply or a lead acid battery can be used to supply total current in one arm equal to 40 ampere to demonstrate the field pattern by iron filings

Fix the coil vertically in the table as shown in Fig.3.11 Let its vertical arm pass through the centres of two horizontal boards fixed on the table Sprinkle fine iron dust on the cardboards Pass a current of 1A in the coil by a 12 volt power supply and tap the cardboards The iron particles arrange themselves in circular loops around the vertical arms of the coil carrying current

APPENDIX 6

Making a circular coil for study of magnetic field produced by it

Take enamelled coper wire, SWG 24 wind it into a circular coil of 600 turns For this purpose make a cardboard spool of about 1 mm thick cardboard of internal diameter 64 mm, outer diameter 96 mm, crossection 16 mm x 16 mm Thus the space available for windings of copper wire is of 14 mm x 14 mm crossection It wil take about 150 metre of wire with a resistance (at 20°C) of about 11 ohm, weighing about 300 gram

Fix the coil vertically in the centre of a horizontal board of about 20 cm x 20 cm size (Fig A-6a) A better shape for the board is an octagon inscribed in a circle of diameter about 28 cm (Fig A-6b). Paint the top surface of the board white. Sprinkle fine iron dust on the board With help of a d.c. power supply,

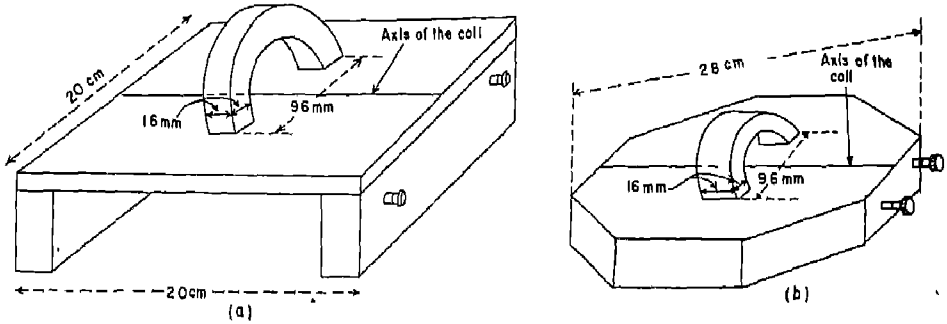


Fig A-6 Circular coil for study of its magnetic field (a) mounted on the square board (b) mounted on the octagonal board

pass a current of about 1 ampere in it at 12 volt, for about 10 seconds While the current is passing, gently tap the board Iron particles arrange themselves into a beautiful pattern of lines of force in the magnetic field of current carrying coil, as its magnetic field is quite strong

You can pass a constant current of about 120 mA in it for quite long continuously by just a dry cell and field is strong enough to be plotted by a plotting compass

You can pass a current of about 500 mA by four dry cells, float it in water (putting it in a trough), and observe its behaviour as a quite strong magnet, which keeps its axis along north-south line

You can connect it to a most ordinary golvanometer Remove it, from its board, hold it in hand and turn through 180° Current induced in it due to changing flux of earth's magnetic field can thus be shown to a whole class.

APPENDIX 7

Making a Solenoid for Study of its Magnetic field

Take copper wire (16 SWG), commonly used for earth connection in domestic electric wiring Enamelled wire will be better On a glass bottle of cylinderical shape and diameter between 5 to 5-1/2 cm, wind 42 turns of this wire close to each other When you take it off the bottle, it unwinds by 4 turns, leaving only 38 turns At the same time, its diameter increases to between 55 mm to 61 mm

Now take a strip of 6 mm thick ply-wood, between 16 to 20 cm long and breadth equal to external diameter of the solenoid (Fig A-7a) Along its longer edges, make 1 5 mm deep grooves at 4 mm spacing (i e 38 grooves in 152 mm length). Insert it into the solenoid such that its upper surface is the horizontal plane passing through the axis of the solenoid (i e height of loops below the lower surface is 6 mm less than height of loops above the upper surface). Put a drop of araldite (or similar adhesive) in each groove and let it harden for 24 hours, thus fixing the solenoid in correct position on the strip

Make a wooden board (30cm x 40cm) in the centre of which is a window whose size is equal to the wooden strip In the two ends of this window there are seats for the wooden strip to rest on Fix the wooden strip on these seats alongwith solenoid wound on it (Fig A-7b) Fix terminals T,T at the ends of the board and connect the two ends of the solenoid to the terminals

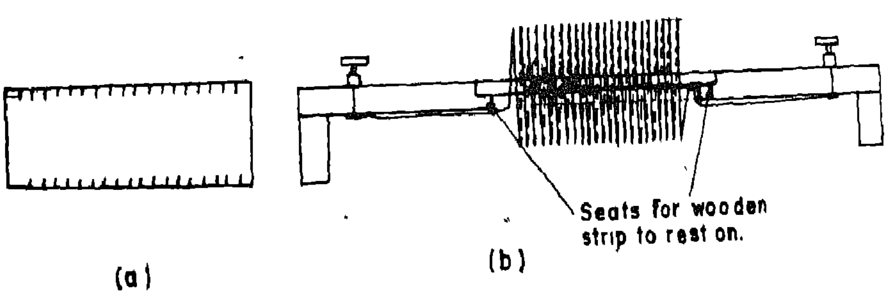


Fig A-7 Solenoid for study of its magnetic field (a) The strip to fix the horizontal plane through its axis (b) Sectional view of the mounted solenoid.

Your solenoid is ready. You can pass a current of up to 10A through it and its temperature rises by only 3°C or 4°C above room-temperature Then a magnetic field of 30×10^{-4}T is produced in it, which

is enough to demonstrate field pattern by iron filings You can pass merely 300 mA by a dry cell to plot the field pattern by a plotting compass Either a 50 mm compass or a plotting compass can be manipulated inside it by a short length of 16 SWG copper wire, which can be introduced through the 2 5 mm spacing among the turns of the solenoid You can plot the points inside for mapping the magnetic field by a ball point refill or a short length of pencil lead plugged at the end of the plastic tube of a used ball point refill

APPENDIX 8

Making a current-carrying coil which behaves as a compass needle and with whose help one can plot a magnetic field, using a single dry cell.

Take a torch cell (1 5 volt e.m.f.). Test its short circuit current, which should be more than 5 ampere, if it is fresh. If you do not want to damage the cell, this short circuit current should not be drawn for more than 3 or 4 seconds This cell is of cylinderical shape having a diamater of 33 mm and length of 60 mm. Make a card-board spool in the core of which the cell just fits Thus the space for winding a coil on it has internal diameter of 35 mm and length of 58mm (Fig A-8) Wind on it enamelled copper

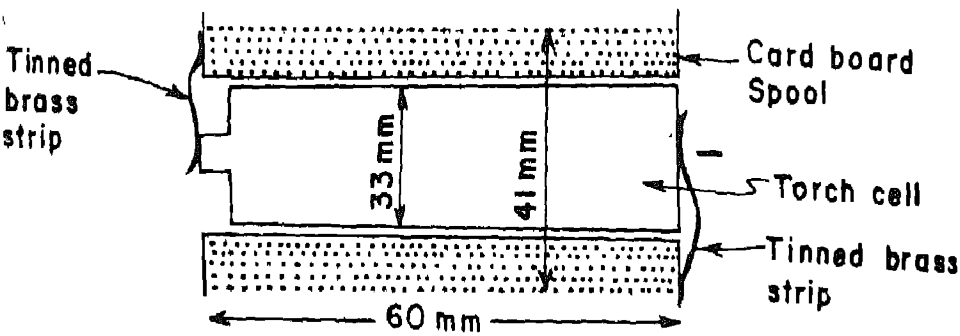


Fig A-8 A coil which can be used as a magnetic needle without any iron in it

wire of SWG 24 in 5 layers of 97 turns each, thus you get an outer diameter of 41mm, use about 59 metre of wire whose resistance is 4 2 ohm at 20°C Ends of the wire are soldered to two tinned brass strips attached in opposite faces of the cardboard spool When desired, you can rotate one of the strips about the point where it is attached to cardboard, insert the cell and bring the strip back, in order to (i) hold the cell in position and (ii) make contact at its ends and thus pass a current of about 350 mA in the coil.

Suspend the coil without cell in the stirrup of a vibration magnetometer Observe that it has no tendency to acquire the north-south direction Now insert the cell in it, so that current passes in the coil The coil starts oscillating about the north-south direction, just like a magnet with a time period of about 1/2 minute Bring it to rest with its axis in the north-south direction and it stays stationery.

This cylindrical "magnet" of 60 mm length and 41 mm diameter (if pivoted in a suitable frame) can be used to find the direction of magnetic field at any point in the field of a magnet or another current

carrying coil Of course, due to its size it is not so convenient as a plotting compass, whose box has outer diameter between 12 mm to 20 mm and height about 5 mm More-over, you can keep your coil "magnetised" for only about 5 minutes at a stretch Then you must remove the cell, give it some rest, test that it is still capable of supplying the current and, if necessary, put another cell

APPENDIX 9

Making a U-magnet out of Two Bar Magnets

Take two strong bar magnets of 5 cm or 7.5 cm length. Also you need an iron block, about, 6 mm or 9 mm high and length and breadth equal to breadth of the magnets. Alternatively cut square pieces of this length and breadth out of an iron sheet. Make sufficient number of pieces of iron sheet, which when put together make about 8 mm to 9 mm thickness

Place this iron block/pile of iron squares over south pole of one magnet. Put the north pole of other magnet over it and tie the two magnets and the iron block tightly together (Fig. A-9) At the other end

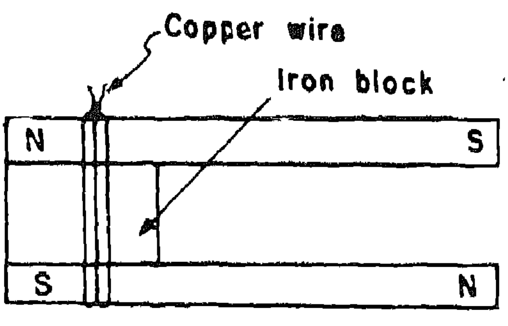


Fig. A-9 A U-magnet made of two bar magnets

north pole of lower magnet and south pole of upper magnet are roughly at same distance apart as the height of iron block. Insert this gap over a Barlow's wheel (experiment 3 25) or over the rotating disc which generates a small d.c voltage in this magnetic field, (experiment 4 6)

APPENDIX 10

Make a Strong Electromagnet out of a Rejected Flourescent Tube Choke

If you have a rejected choke of your fluorescent tube light, don't throw it away It is going to be useful for your science experiments.

Open up the casing of the choke. Inside you have a choke, the core of which is as shown in Fig A-10a

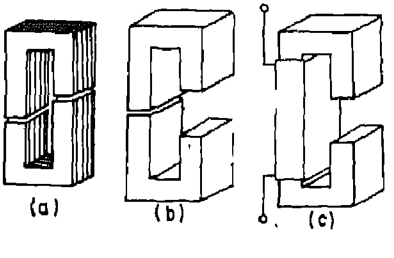


Fig A 10
(a) Core of fluorescent tube choke
(b) Re-arrange the two parts to make a C-core
(c) The complete electromagnet.

There are two J-shaped piles of laminations each having a coil wound over it and both coils are connected in series In the rejected choke, one of the two coils is probably burnt out Select the one which is not burnt and throw away the other coil

Now join the two J-shaped cores as shown in Fig A-10b so that you have a C-shaped core Insert the longer leg of the J-cores into the coil till the two legs touch inside the coil (Fig A-10 c) If you pass a d.c. current in the coil by a 24 volt power supply a strong magnetic field is formed in the gap

You can do many other interesting things with this burnt out choke, which are described in the following booklet:

Datta, S N., *Low cost Electromagnetic Induction Kits out of the Condemned Chokes of a Fluorescent Tube* Mysore, Regional College of Education, NCERT, 1986

APPENDIX 11

An Inductor of High Inductance and Low Resistance

The coil of this inductor is to be wound on a cardboard spool into which a core of rectangular cross-section (50 mm x 75 mm) can be inserted The core consists of E-shaped laminations, the central arm being 50 mm broad and the stack is built up to a thickness of 75 mm (Fig A-11) Length of central arm of each

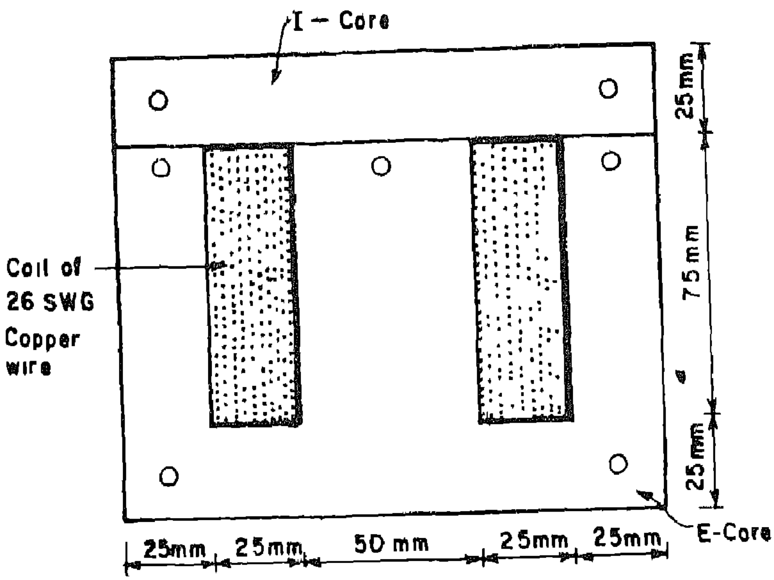


Fig A-11 An inductor of large time-constant

lamination is 75 mm. Thus length of cardboard spool is 74 mm (outside) or 72 mm (inside), thickness of 1 mm for cardboard being an appropriate value.

Wind 43 layers of windings by 26 SWG enamelled copper wire The winding should withstand an a c voltage of 1000 volt applied to it This can happen when free oscillations are set up in it with a condenser in parallel with it (experiment 4 27) Hence 72 mm length of spool be divided into three sections by walls of a good insulating materials The three coils are wound one in each section, each having 43

layers and 45 loops in each layer and the three coils are in series. Thus inside of this winding has 52 mm x 77 mm rectangular crossection and the outside has 98 mm x 123 mm crossection. Entire winding requires about 2388 m of 26 SWG wire, weighing about 3¾ kg and having resistance of about 250 ohm at 20°C

The E-shaped core has central arm of 75 mm x 75 mm x 50 mm and outside arms of 75 mm x 75 mm x 25 mm with 25 mm gaps. Thus total length of core is 150 mm. Open pace of E-core is closed by an I-core of 150 mm x 75 mm x 25 mm so that entire magnetic circuit is in the iron core with negligible air gaps (at contacts of I-core & E-core) It weighs about 9 kg Thus total weight of the inductor is about 12 4 kg.

Permeability of iron for small fields (i e for small currents ~ 0 1 mA in the coil) is about 300 and thus inductance of this inductor is roughly 150 henry. The maximum permeability is more than 5000 at a field of the order of 2 oersted (obtained by a.c current of peak value 8 mA, for which the inductance is as high as 2500 henry

Special Applications of this inductor include the following.

(i) Demonstration of the fact that on application of a d c voltage, the current passing through an inductor takes time to reach its steady value. Due to large $\frac{L}{R}$ of this inductor (~10 s), the slow rise of current is clearly seen (Expt 4 20)

(ii) Demonstration of dependence of L on maximum current using a source of d.c voltage. If maximum current is 100 μA and is measured by a micro-ammeter, rise of current is much faster. For maximum current of 8 mA, rise is quite slow

(iii) Connected in parallel with a 2 μF paper capacitor and excited by a 2 volt accumulator, it creates free electrical oscillations for several seconds, showing that it makes an oscillatory circuit Current flows to and fro with a frequency of 2.25 Hz, starting at about 300 volt peak value across the capacitor, which can be demonstrated by a neon indicator lamp in series with a 5MΩ resistor (Expt. 4.27). In similar manner, free oscillations in the series L-C circuit can be demonstrated by charging the condenser by a 300 volt d.c power supply, (Expt. 4 26)

(iv) The coil alone makes a large air core inductor of about 1 henry With its inductance remaining constant over a wide range of current and frequency, quite a number of experiments and demonstrations can be done by it

(a) Voltage-current relationship for constant f and the concept of impedence can be studied without an audio-oscillator, merely by using 50 Hz a c. Due to large L, inductive reactance is large enough at 50 Hz in air core only. Thus V-I graph is precisely a straight line, which may not be so with iron core.

(b) Series and parallel resonance experiments can be done without an audio-oscillator, merely by using 50Hz a c and the same capacitor of 2 μF Resonant frequency for this capacitor with this completely air cored inductor is

$$f_r \approx \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2 \times 3\ 14 \sqrt{1 \times 2 \times 10^{-6}}} = 112 \text{ Hz}$$

By bringing the E-core alone to the coil, its L will increase, the actual value of L depending strongly on the relative positions of the coil and the E-core. Maximum values of L is obtained when E-core is completely inside the coil, when its distance from the core may be taken as zero. Since, it may be difficult to calibrate the distance between the two in terms of the value of L, the distance itself may be used in place of the value of L, to plot the various graphs for the study of resonance phenomenon

(c) Study of phase relation between impedence of the air cored coil and a resistance in series with it by constructing the voltage triangle, finding the resistive and reactive components of its impedence and thus demonstration of the equality of this resistive com-

ponent to the d.c resistance of the coil may be done (Due to its air core, there are no other energy losses than the heating of the copper winding At 50Hz, the energy radiation in the form of electromagnetic waves is also negligible There is no skin effect too).

(d) Demonstration of eddy currents in a conductor placed near it may be done without the iron core Place the coil with its axis vertical Place on its horizontal face, an aluminium sheet of size 100 mx 125 mm, which fits the outer boundary of the coil Apply 230 volts a c to the coil from your a.c mains. An a c of about 0 6 ampere passes in it Due to induced eddy currents, the aluminium sheet is repelled and is thrown off As the power consumptions in the coil is about 150 watt, it gets heated quickly and the current may not be passed for more than a few seconds

APPENDIX 12

Make a Fine Slit of Uniform Width Equal to Thickness of a Razor Blade

On a glass sheet of at least 60 mm x 60 mm, place another glass plate of same size, which has been cut into two parts A and B (Fig A-12 a) A and B are separated by a distance equal to thickness of blade C, which stands vertically between them with its sharp edges vertical Stick end portions of A and B together by adhesive tape so that these are not pushed apart during subsequent work About 50 mm length of A and B is clear from the adhesive tape (Fig A-12 b) Next place two new blades D and E, one sharp edge of each touching the blade C. Now stick the end portions of D and E together by adhesive tapes T,T

Next put the assembly of D and E upside down. Fold the extra breadth of tapes T, T onto the side which is now upwards If this assembly is to be made permanent then, instead of folding the adhesive tape, use small pieces of blade coated with a strong adhesive (like araldite) on this side of the assembly Then this assembly of D and E has a slit of uniform width equal to thickness of blade C and length more than the width of blade C.

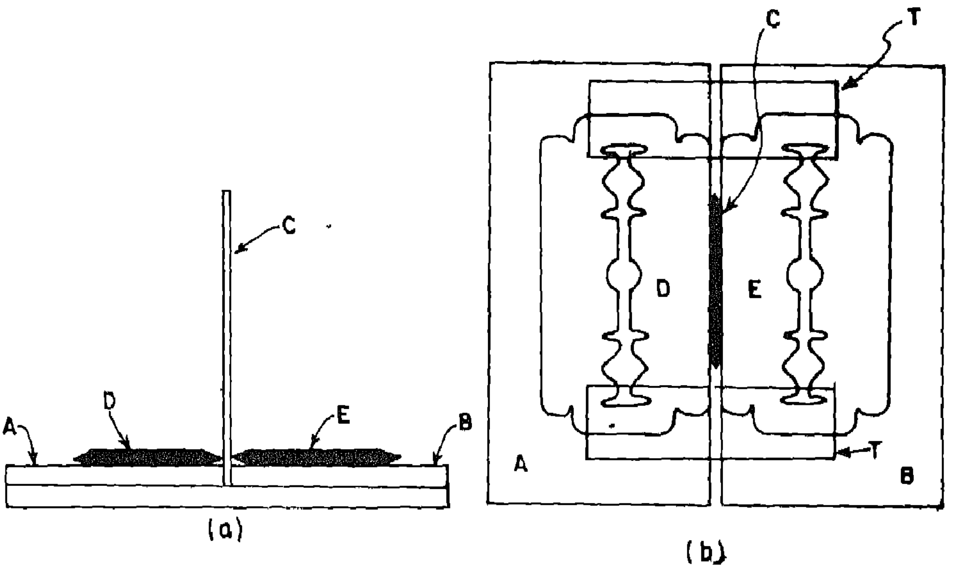


Fig A-12

APPENDIX 13

Making a Simple Double Slit for Young's Experiment

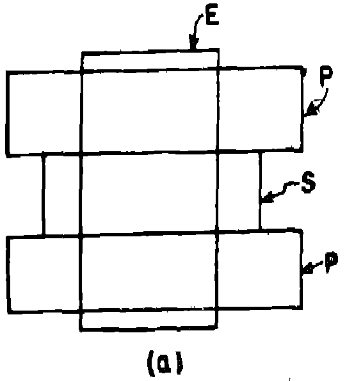
Take a microscope slide. Clean it with soap and water and let it dry Check that the glass has no ripples visible with naked eyes. (Look at a distant object through it and move it in its own plane If the distant object is seen shaking, the slide has ripples, and is not made of good glass)

Now paint the slide with graphite colloidal suspension, or black water proof ink used by the artists, or just deposit soot by keeping over a candle flame. Take two razor blades Hold them together with thumb and fore-finger, close to corner and make a pair of lines on the slide by this corner. The separation between the two lines, A and B (Fig A-13 b) is equal to thickness of one blade If you hold far from this corner, then while drawing the lines, the blade may separate out and separation between the lines may increase at some places, wherever the blades separate out

You must draw the lines in a single effort and with such a pressure that the glass becomes transparent at the lines For this reason it is advisable to start with four to five slides, make lines on each and then select the best one by viewing through each at a line source of light Arrangement shown in Fig A-13a is helpful for drawing pair of lines straight and in correct place and direction The slide S is held between two slightly thicker glass plates P, P. The three are stuck together by an adhesive tape on their lower faces which are in contact with working table Then a small straight edge E (it can be another glass plate with edge ground or a plastic scale) is supported on the plates PP, so that it remains clear above the coated surface Then the pair of lines is drawn by the blades along the edge E

A slide coated with graphite colloidal suspension or water proof ink may be viewed from any side However, the slide on which soot is deposited must be held with uncoated side towards the eyes, lest a contact with your face may spoil the slide

In order to be able to see a metre-scale through it, alongwith the diffraction pattern, make a clear window, W, of about 5mm x 5mm (or a circle of about 5mm diameter) in the middle of the pair of lines A & B (Fig A-13b) The best way to make the window is to stick a small piece of adhesive tape on the slide before painting it. After painting it, peal off the piece of tape carefully by the tip of a knife The tape must be of a good quality, so that it leaves no spot on the glass after it is peeled off



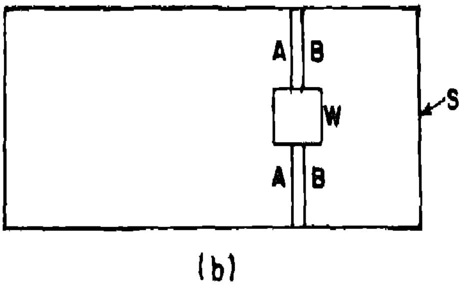


Fig A-13

APPENDIX 14

* Mechanical Analogue of Scattering of α - Particles by Atomic Nuclei

Principle

The potential at a point in an inverse square force-field (as is that of the nucleus of an atom) is inversely proportional to the distance from the point source of field. If the force is repulsive (as it is between the nucleus and an α-particles), the potential is positive and a graph of $1/r$ versus r represents the variation of potential with distance (Fig A-14a) If we revolve this curve about the Y-axis (Fig A-14b) the solid of revolution of this curve is obtained Top surface of this solid, the surface of revolution of the curve gives a mechanical model of the potential hill (Fig A-14c).

A ball rolling up this potential hill acquires a gravitational potential energy proportional to h and, therefore, proportional to $1/r$ Thus its motion simulates the motion of particle moving in 2-dimensions under a repulsive inverse square force-field Thus it simulates the motion of a charge moving on the plane in the electric field of the nucleus.

Construction of the Model

A typical model of potential hill can have a base diameter of 28.2 cm, and a top diameter of 4cm and

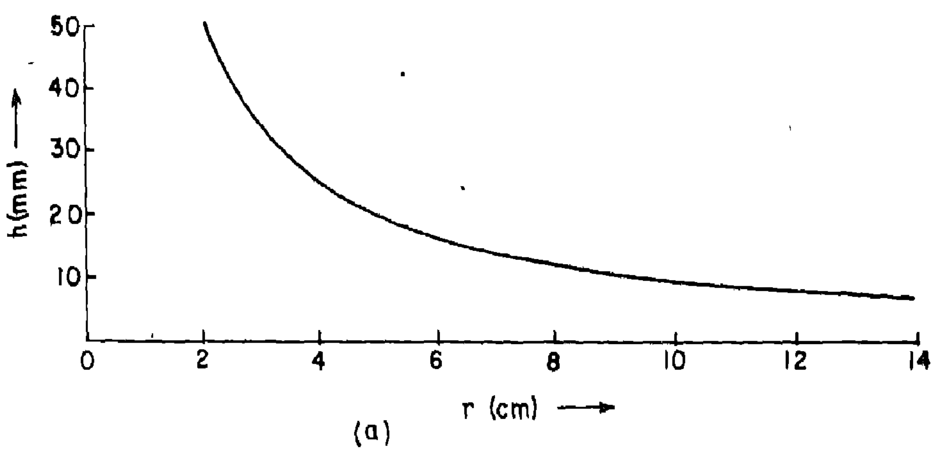


Fig A-14

height of 50mm (Fig. A-14d) The model can be turned out of wooden plank 30cm x 30cm x 5cm First, a curve between h and r (Fig A-14a) is drawn on a graph sheet (of size larger than 10 cm x 15 cm) with the following points

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*Material for this appendix was provided by Dr.N.N. Swamy, Reader in Physics, Regional College of Education, Mysore-570 006

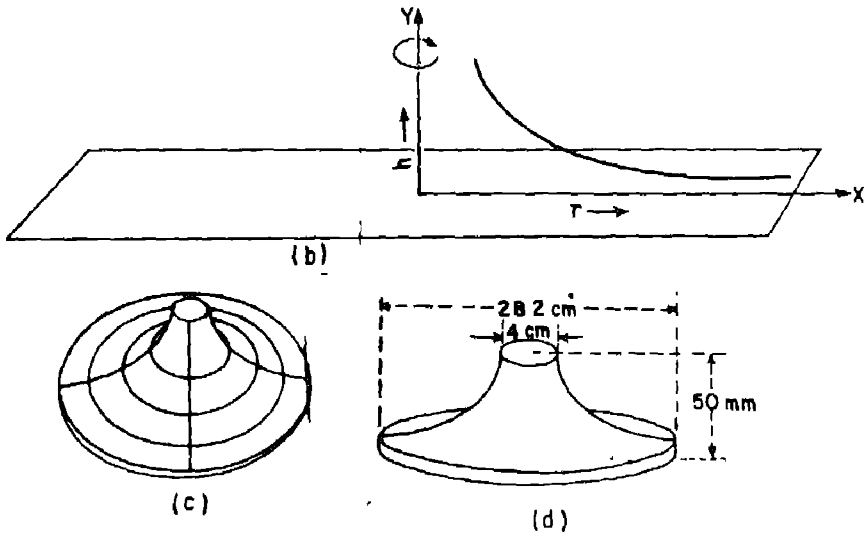


Fig A 14 (b, c, d)

X (r) cm	14 1	12.5	11 1	10 0	9.0	8 0	7 0
Y (h) mm	7 0	8 0	9.0	10 0	11 1	12 5	14 1
	6 0	5 0	4 0	3 3	3 0	2 5	2 0
	16 7	20 0	25 0	30.0	33 3	40 0	50 0

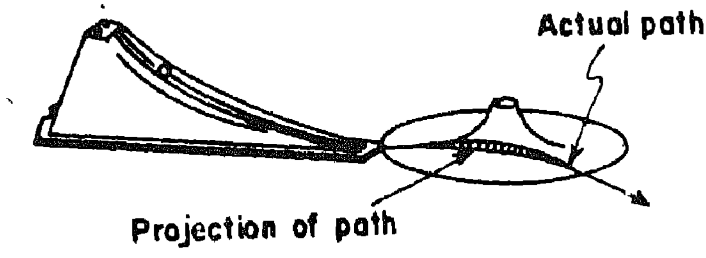
The graph is shown in Fig 1 for reference To make an accurate and smooth curve, it is better to use the instrument 'FLEXIBLE CURVE" used by artists A template is cut to fit this curve Using this template, the solid of revolution is cut on the wooden plank fixed to a lathe

Accessories

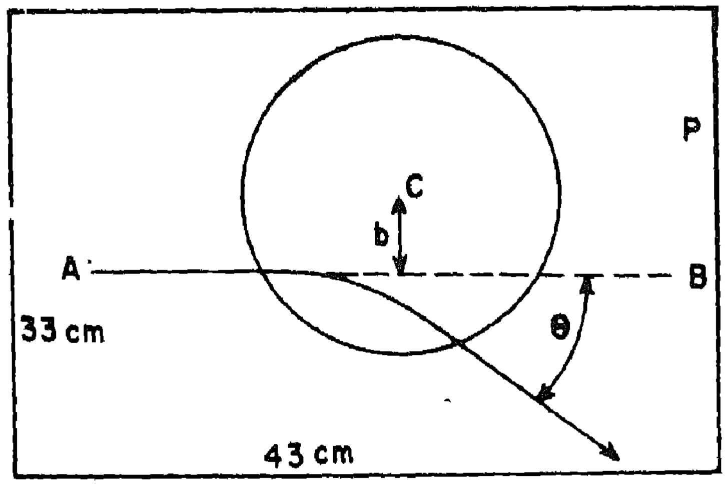
1 Steel balls of 12 7 mm diameters
2. A ramp to roll down the balls from different heights (accelerator) A 30 cm plastic scale will be suitable Height of lower end of ramp must be equal to height of the lower boundary of the potential hill, so that a ball rolling down the ramp smoothly rolls onto the potential hill without any jump In order that the rolling ball represents high energy α-particles, upper, end of the ramp should be of height 12cm or more The scale must be fixed in a curved shape, with its lower end horizontal, so that the ball leaving the lower end after rolling down, smoothly rolls on to the potential hill without any significant change in the angle of its motion with respect to horizontal plane

Experiments with the Potential Hill

In the two experiments described below, the model is to be used as a potential hill to demonstrate the different aspects of alpha scattering The ramp should be kept with its edge touching the surface of the hill at its lower boundary (Fig A-14c) The ball should be held on the ramp at the desired height with a stopper (A flat scale will do). The ramp should be placed along a direction off the centre C, such as



(e)



(f)

Fig A-14 (e, f)

AB in Fig.A-14f to trace the path of the ball a paper P, of size 33 cm x 43 cm with a carbon sheet of same size above it is fixed on a large drawing board or plane and smooth table top, which is adjusted horizontal The model and the ramp can be placed on this paper for both experiments.

Experiment 1: Dependence of the scattering angle (θ) on the initial energy of the particle

Release the ball from different heights on the ramp and show that the scattering angle (θ) increases as the initial energy decreases.

Experiment 2 The relation between the scattering angle and the impact parameter for a given energy of the alpha particle.

Release the ball from a specified height and determine the scattering angle θ. Measure also the impact parameter *b* (see Fig A-14f). Repeat the experiment for different values of '*b*' but always releasing the ball from the same height. Measure the scattering angle in each case.

Show that $b \propto \cot \theta/2$, as illustrated in Fig 13.7 of the textbook.

SUGGESTIONS FOR THE SCHOOLS

A number of demonstration experiments that make the chapters of modern Physics interesting need resources which are at present not available in a number of physics laboratories of schools and even junior colleges where Physics is offered by the students at the +2 stage It is suggested that the teachers should arrange for demonstration lectures by subject experts from a nearby Degree College/University/Research Laboratory If need be they may seek the help of school authorities

Some of the schools and junior colleges may be lucky to have a 16 mm projector and or a TV with or without VCP, Central Institute of Educational Technology (CIET), NCERT, New Delhi has a number of 16mm educational films on Physics topics Schools can become members of this library to obtain on loan suitable films, specially those dealing with the topics under modern Physics. Schools may have the catalogue/information about the films and video cassettes by contacting the officer Incharge Film Library, CIET, NCERT, New Delhi PIN-110 016. If teachers obtain on loan suitable films/video cassetts they should make their best use Viewing of the general TV programmes, specially those telecast under the UGC TV Programme in science related to Physics may also be found helpful Other teachers should be on the look-out for opportunity to arrange a visit to the nearby Science Centre/Science Museum/ Research Laboratory after making a prior arrangement with an expert for setting up some of the experiments connected with the course In such a case the interaction of students with the experts should be encouraged and some advance preparation and a follow-up would become necessary, by the teacher in the class

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